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Translocation and Persistence of Cycloheximide (Acti-Dione) in White Pines

BY
A. J. LEMIN
W. KLOMPARENS
V. D. MOSS

THE ABSORPTION, translocation, and persistence of antibiotics in tissue of several plant species have been recently summarized by Goodman (Goldberg, 1959). For example, the antibiotic streptomycin has been shown to persist for at least 1 year in the trunk of a Winter Nelis pear tree (Ark and Alcorn, 1956). Similarly, the persistence of cycloheximide in wheat plants (Wallen and Millar, 1957) and in cherry fruit (Prescott *et al.*, 1956) has been determined. In wheat, cycloheximide could be detected in foliage 5 weeks after a single application to the roots, and in cherries, the half-life was about 24 hours. Selective adsorption and retention by wood tissue of basswood was reported in 1950 (Klomparens). A literature survey of the agricultural use of cycloheximide has recently been published (Ford *et al.*, 1958).

Control of cherry leafspot, *Coccomyces hiemalis* Higgins, on Montmorency cherry, has been used extensively as a basis for study of the absorption, translocation, and persistence of cycloheximide and its derivatives. The initial publication (Hamilton *et al.*, 1956) described systemic disease control following foliar applications of cycloheximide derivatives. Subsequently Hamilton and Szkolnik (1958) and Szkolnik and Hamilton (1959) reported on systemic control following soil applications of cycloheximide and its semicarbazone. They noted that the derivative showed significantly greater persistence in the soil, thus prolonging the systemic fungicidal action. Unpublished data by these workers shows striking systemic control when cycloheximide and the semicarbazone were used as root dips. Lesser control was obtained when they were applied in oils or with surfactants to the bark of dormant Montmorency cherry.

Using the semicarbazone and acetate derivatives, Hacker and Vaughn (1957, 1958) demonstrated systemic control of black stem rust of wheat, *Puccinia graminis tritici* Ericks. and Henn. Phelps *et al.* (1957) reported that cycloheximide and its acetate delayed symptom expression of oak wilt, *Ceratocystic fagacearum* (Bretz) Hunt., for at least 3 months. Lewis and Hickey (1959) reported that surgery followed by 400 ppm cycloheximide treatment controlled black knot cankers, *Dibotryon morbosum* (Schw.) Theissen and Sydow, on Stanley prune. Treatment was effective from May through August, but not in March.

The etiology of white pine blister rust,

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Cronartium ribicola Fischer, has been well described by Mielke (1943). The economic importance of the disease may be gauged by the fact that over the last 5 years an average of 3¾ million dollars has been spent annually by states, private landowners, and the Federal Government on control.

The current method for large-scale blister rust control is the mechanical and chemical removal of the alternate host, *Ribes* (Offord *et al.*, 1952; Moss and Wellner, 1953). Eradication of ribes is an expensive and time-consuming procedure entailing the removal of the alternate host within a white pine stand as well as over a surrounding "protective zone" 200 to 1000 feet wide. Removal of the alternate host around highway, estate, and other small pine plantings often cannot be economically justified.

The discovery in 1953 that the antifungal antibiotic, cycloheximide (Acti-dione),[1] has an eradicative effect on active blister rust infections on western white pine gives promise of an added tool for the control of this disease (Moss, 1957). Using the excision method (Martin and Gravatt, 1954) with modification prior to applying cycloheximide, Moss (1958) controlled blister rust on western white pine, *Pinus monticola* Douglas. Barring unforeseen complications, the use of cycloheximide makes possible the preservation of thousands of acres of forest pine stands which became infected before *Ribes* were eliminated. The new direct technique should also be applicable to smaller plantings along highways, in parks, and around residences. Recent observations by the authors indicate that the use of cycloheximide might be extended to the control of blister rust on other 5-needle pine species such as eastern white pine, *P. strobus* L., whitebark pine, *P. albicaulis* Engelmann, limber pine, *P. flexilis* James, and sugar pine, *P. lambertiana* Douglas. Strong (1957) reported control of sweet fern rust, *Cronartium comptoniae* Arth., on Austrian pine, *P. nigra* Arnold.

First using a basal stem method of application in 1957, the authors observed that trunk and branch infections above the area of direct application were killed as well as those sprayed directly with the antibiotic. Thus, the observations on disease control indicated that cycloheximide was translocated upward in the trunk in quantities sufficient to eradicate the pathogen located above the site of application.

The studies described here investigated the translocation and the persistence of cycloheximide in western and eastern white pine. Direct analytical methods of paper chromatography and bioassay were employed instead of disease control to determine the presence of cycloheximide in plant tissue.

Western White Pine: Procedure

The tissue samples were from two different treatment series on polesize pine. One series (collected from ½ to 128 days) was from a plantation in the Kaniksu National Forest, Idaho. These trees had been treated with 120 ppm of the antibiotic as part of the blister rust control program (Viche and Kapel, 1957, 1958)[2] by national forest crews in the northern Rocky Mountains. The second series (collected after 9 months, 1 and 2 years) was a 200 ppm treatment, applied in an adjacent area in 1957 and 1958 as the chemical control method was being developed. In Experiments 1 and 2 described later, samples from both treatment series were used.

Basal Stem Application of Cycloheximide

Standard solutions (4 percent) of cycloheximide in cyclohexanone were diluted to the desired concentrations with No. 1 fuel

[1]The Upjohn Company, trademark for the antibiotic cycloheximide.

[2]H. J. Viche and F. J. Kapel. A progress report on the treatment of blister rust trunk cankers on western white pine with Acti-dione on a project basis, Kaniksu National Forest, Forest Service, U. S. Dept. Agric. report, 1957. Second report with similar title, 1958.

(stove) oil.[3] The mixture was sprayed on the trunks of trees up to 12 feet in height, as far up as the lowest one-third of the crown height. Trunks of trees over 12 feet high were sprayed up to about 5 feet or eye level. The inner 12 to 18 inches of the branches starting from the treated trunk segment were also sprayed. Delivery of the spray mixture was just to the point of runoff.

Two concentrations were employed:

1. A cycloheximide 200 ppm solution was used and samples collected 9 months, 1 and 2 years after treatment.
2. A cycloheximide 120 ppm solution was similarly applied and samples collected ½, 1, 2, 4, 8, 16, 32, 64, and 128 days after treatment.

Collection of Samples

Tissues from the treated trees were packed in polyethylene bags at the site of collection in Idaho and immediately shipped to Kalamazoo, Michigan. Samples were in transit 3 to 5 days and when received were stored at −5° C until they were extracted. The samples from various parts of the trees were:

(a) *Lower bark tissue:* the bark from the treated area of the trunk.

(b) *Upper bark tissue:* the bark from the trunk of the treated tree above the cycloheximide treated area. Random collection, including bark tissue from as high as 25 feet above the ground.

(c) *Lower needle tissue:* careful selection of unsprayed needles from treated branches arising from the treated portion of the trunk.

(d) *Upper needle tissue:* needles on untreated branches originating from the untreated portion of the trunk above the treated area. Random collection, including needles from branches as high as 25 feet above the ground.

(e) *Lower xylem tissue:* chips of xylem from the lower, treated trunk area after the bark had been stripped. The chips were obtained from lathe turnings to a depth of ¼ inch.

(f) *Upper xylem tissue:* chips of xylem from the upper, untreated trunk area, after the bark tissue had been removed, were collected as just described.

Extraction of Samples

A weighed sample of the bark, needle or xylem tissue, usually about 400 grams, was placed in a 1-gallon "Waring Blendor" and 1.5 liters of water added. The tissue was macerated for 10 minutes and filtered through two sheets of Whatman No. 4 paper. The residue, with the filter paper, was again macerated in 1.5 liters of water for 10 minutes and filtered. The combined filtrates were shaken three times, each with 150 cc of methylene chloride and the organic phase then separated from the aqueous phase. With the needle samples, centrifuging was usually necessary to separate the phases. The methylene chloride was removed under reduced pressure with gentle heating on a steam bath.

In order to determine the efficiency of the water extraction, the pulp remaining after the water extraction was re-extracted with 2 liters either of methanol or acetone. The filtrates of these were reduced to about one-tenth of the original volumes by evaporation. One liter of water was added to each sample, which was then extracted three times each with 150 cc of methylene chloride. The solvent from the combined methylene chloride phases was removed as previously described and the presence of

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[3]Federal Specification: FUEL OIL, BURNER.

Grade No. 1 Stove: A volatile distillate oil for use in burners preparing fuel for burning solely by vaporization. Flash point °F 100 min. Carbon residue on 10% residuum percent 0.08 max. Distillation temperature °F, 10% point, 420 max. End point °F 625 max. Viscosity, kinematic centistokes at 100° F, 2.2 max., 1.4 min. Gravity °A.P.I., 35 min. Ash content 0.01 percent. BTU 19,500.

cycloheximide determined by papergram analysis and bioassay. Neither the methanol nor the acetone extraction produced more cycloheximide than that which could be detected by the water extraction method.

Paper Chromatography of the Extracts

The methylene chloride residue was dissolved in 1.0 cc of methanol by warming gently on a steam bath. One-half of the cooled solution was used for papergrams and the remainder reserved for bioassays. The solution (0.1 cc) was spotted on Whatman No. 1 paper along with one microgram of cycloheximide for use as a standard. The paper was equilibrated overnight and then developed for about 6 hours with the upper phase of a mixture of one part benzene, one part methanol, and two parts water. After drying, the paper chromatogram was placed on an agar tray which had previously been inoculated with the assay organism, *Saccharomyces pastorianus*, (Whiffen, 1948). The papergram was incubated overnight at 37° C and then removed from the agar plate. A typical example of inhibition zones is shown in Figure 1. By this method, 0.1 microgram of cycloheximide could be detected and identified.

Bioassay of the Extracts

If cycloheximide was detected by the paper chromatography technique, the remaining methanol solution of the extract was bioassayed to determine the concentration of antibiotic (Whiffen, 1948). Samples from untreated plants were bioassayed and occasionally these exhibited small positive values. The statistically significant difference between samples at 95 percent confidence level was ± 32 percent as determined using pure cycloheximide. The assay solution must contain 2.0 to 7.5 micrograms per cc. Any value below 2.0 micrograms per cc was therefore recorded as "trace." Samples assaying in excess of 7.5 micrograms per cc were diluted with water and reassayed.

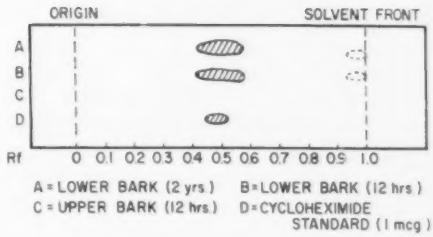

FIGURE 1. *Inhibition of* Saccharomyces pastorianus *from papergrams of extracts from cycloheximide-treated western white pine bark samples.*

Percentage Recovery

Known amounts of cycloheximide (5 to 50 micrograms) were added to 400-gram samples of untreated western white pine bark and eastern white pine needles. These were extracted in the manner described. Bioassays showed consistent recovery of 12 to 15 percent of the added antibiotic. The mean (13.5%) was the basis of the conversion factor ×7.4, applied to all subsequent bioassay data.

Analysis of Different-Aged Needles

A supplementary test was made to determine whether there was variation in the amount of cycloheximide retained in needles of different ages, since the antibiotic had previously been found in the needles of both tree species treated. In this small scale trial, the lower and upper needles from a western white pine treated with 150 ppm of the antibiotic in cyclohexanone–No. 1 fuel oil were collected 1 month after treatment and the 1-, 2-, and 3-year-old needles were separately extracted and analyzed by bioassay.

Western White Pine: Results

Experiment 1

In the first preliminary experiment, samples of the lower bark, upper bark, lower needles, and upper needles were collected and analyzed ½, 1, 2, 4, 8 days, 9 months, 1 and 2 years after treatment. The experiment gave these results:

Lower bark. Cycloheximide was present in all lower bark samples up to and including the 9-month sample. The maximum concentrations (0.16 ppm) were in the samples collected ½ and 1 day after treatment. Thereafter, the concentration tended to decrease. Traces of the antibiotic were found in the 2-year sample.

Lower needle. Cycloheximide was detected in the lower needle samples up to 8 days after treatment but not in the 9-month and subsequent samples. The maximum concentration (0.04 ppm) was found in the 4-day sample.

Upper needle. Only trace amounts of the antibiotic were found and then only in those upper needle samples collected ½ and 1 day after treatment.

Upper bark. Cycloheximide was not detected in any of the upper, untreated bark samples.

Untreated. Samples of the lower, untreated bark occasionally contained traces of an unidentified substance that gave weak inhibition zones on the papergrams. These zones were located near the solvent front of the papergrams (Rf 0.9 to 1.0) and hence did not interfere with the detection of cycloheximide (Rf 0.4 to 0.5). On the bioassay plates, the extracts also produced small inhibition zones; however, these did not interfere with the cycloheximide assays.

Experiment 2

A second experiment (Table 1) confirmed and extended the observations made in Experiment 1. Pole-size western white pines were treated with a 120 ppm solution of cycloheximide in cyclohexanone–No. 1 fuel oil as previously described. Samples of the upper and lower bark, upper and lower needles, and upper and lower xylem were collected 1, 2, 4, 8, 16, 32, 64, and 128

TABLE 1. Cycloheximide in lower bark and lower needles of western white pine as determined by paper chromatography and bioassay.

Sample	Time elapsed between treatment and collection	Cycloheximide (ppm)	Papergrams[1]	Bioassay—calculated as ppm cycloheximide in tissue
Lower bark	1 day	120	+	0.83[2]
Lower bark	2 days	120	+	1.11[2]
Lower bark	4 days	120	+	0.74[2]
Lower bark	8 days	120	+	0.46[2]
Lower bark	16 days	120	+	0.13[2]
Lower bark	32 days	120	+	0.04
Lower bark	64 days	120	+	Trace
Lower bark	128 days	120	+	Trace
Lower bark	1 year	200	+	0.06
Lower bark	2 years	200	±	Trace
Untreated bark	.....	.....	...	0.0[3]
Lower needles	1 day	120	—	0.0[3]
Lower needles	2 days	120	+	0.09
Lower needles	4 days	120	+	0.07
Lower needles	8 days	120	+	0.04
Untreated needles	.....	.....	—	0.0[3]

[1] + = Cycloheximide present.
— = Cycloheximide absent.
± = Trace of cycloheximide (<0.04 ppm).
[2] Average of two assays.
[3] Occasionally, small positive bioassays were obtained. These were due to a naturally occurring antifungal material which gave papergram spots at Rf 0.9-1.0 (see Fig. 1).

days after treatment. Samples of trees treated with 200 ppm of cycloheximide were collected 1 and 2 years after the application. These samples, as well as the long-term samples used in the preliminary experiment, were collected from a stand where the blister rust infections had previously been killed after basal-stem treatment with cycloheximide.

Lower bark. Cycloheximide was again found in the bark from the treated parts of the trees and persisted for at least 2 years. The quantitative analyses confirmed the trend found earlier; that is, there is a rapid uptake of the antibiotic with concomitant loss from the site of application (Fig. 2).

Apparently the compound is absorbed in the bark, not merely retained on the surface. The bole of a tree, felled 1 year after treatment, was scrubbed vigorously with a brush and liberal amounts of hot water. Bark samples were collected and analyzed by the usual method and found to contain concentrations of cycloheximide comparable to those found in the unscrubbed samples.

Lower needles. Lower needles from treated plants contained maximum concentrations of cycloheximide 2 to 4 days after treatment; reduced amounts were found 8 days after treatment. None was found in subsequent samples.

Upper needles. Traces of the antibiotic were also detected in the upper needles until 8 days after treatment.

Upper bark. The upper bark samples did not contain antibiotic.

Upper xylem. Traces of the antibiotic were detected in the upper xylem until 4 days after treatment.

Lower xylem. Traces of the antibiotic were detected in the lower xylem until 16 days after treatment.

Untreated. As previuosly described in Experiment 1.

Needles of Different Ages

No cycloheximide was recovered from upper needles of any age, and there were no significant differences in the concentrations of antibiotic found in lower needles 1, 2, and 3 years old. The data in Table 2, however, confirm those in Table 1 in that cycloheximide was translocated from the basally treated area to untreated lower needle tissue.

Of interest is that these concentrations, as long as 30 days after application, were 2 to 3 times greater than were previously found in the lower needles collected 2 days after application (Table 1). Further, the

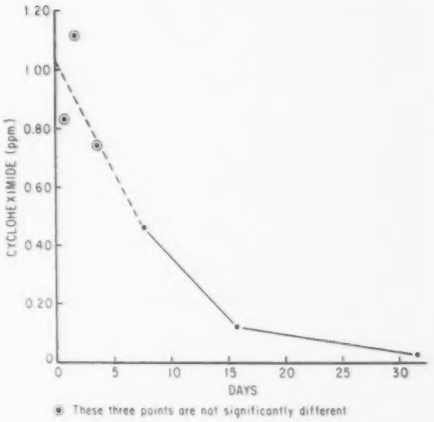

FIGURE 2. *Progressive loss of cycloheximide from the treated bark of western white pines as determined by bioassay with* Saccharomyces pastorianus.

TABLE 2. Recovery of cycloheximide translocated from the treated trunk to untreated 1-, 2-, and 3-year-old lower needles of western white pine. Determinations made 30 days after treatment.

Age of needles	Position	Translocated cycloheximide (ppm)
1 year	Lower	0.15
2 years	Lower	0.22
3 years	Lower	0.22

antibiotic was present in detectable quantities at least 3 to 4 times as long as in the previous western white pine experiments.

All collections previously described were from smooth-barked, pole-sized western white pine. The tree from which these particular collections were made was an older western white pine beginning to produce rough, scaly bark. It required perhaps 5 times as much sprayed solution to bring this rougher bark to the point of visible saturation. The increased persistence can perhaps be attributed to a higher volume of spray delivered.

Eastern White Pine: Procedure

Three 15-foot-high eastern white pine trees in a Michigan plantation were treated with 18 cc per tree of a 500 ppm solution of cycloheximide in No. 1 fuel oil plus 5 percent of cyclohexanone. The solution was applied with a paintbrush completely around the lower 5 feet of the trunk. The 12 to 18 inches of branch tissue was not treated as it was on western white pine. The needles were sampled (200 grams per sample) 1, 2, 3, 7, 24, 31, and 43 days after application. Needles from the inner 3 feet of the branches were analyzed separately from the needles of the outer parts of the branches.

Eastern White Pine: Results

Inner needles. Papergrams indicated the presence of trace amounts of cycloheximide in the inner needles from 2 to 24 days, but not after 31 days. Bioassays showed only trace amounts of the antibiotic; that is, less than 0.07 ppm in the 200-gram samples.

Outer needles. Cycloheximide was not detected until the 24th day. None was detected after that time.

The 500 ppm solution did not produce toxic symptoms in the needles, but gave a temporary yellow mottle on the treated bark. Oil may have been a contributing factor, but no trees were treated with oil alone.

In spite of the higher concentration used on the eastern white pine (500 ppm) compared with that generally used on western white pine (120 ppm), the antibiotic was somewhat less readily translocated to needles of eastern white pine. Only a trace was found at 4 days in the eastern species compared with 0.07 ppm at 4 days in western white pine. The different application technique could account for the variation. Twelve to 18 inches of branch tissue was treated on western white pine; none on eastern white pine.

The higher concentration applied to eastern white pine seems to have served as a reservoir which continued to furnish cycloheximide to needle tissue for a longer period, 24 days in eastern white pine compared with 8 days in western white pine. From these data, it appears that if 500 ppm solutions were applied to western white pine, the higher concentration might furnish cycloheximide to needle tissues for periods longer than the reported 8 days.

Implications for Blister Rust Control

The persistence of cycloheximide in western white pine for at least 2 years could lead to prolonged control of blister rust. If there is continual or sporadic translocation from the site of application into the foliage, needle infections could be prevented or eradicated before the fungus becomes established in the bark. On established infections such delayed activity has, in fact, been observed. Complete kill of trunk and branch infections above the basally treated area often does not occur until 18 to 24 months following application.

All blister rust infections in the bark above the treatment area are killed even though no antibiotic was detected in this upper bark. It is possible that undetected trace quantities were present in sufficient concentrations to prevent the growth of the fungus or that significant quantities were present at times other than when the samples were collected. Another possible explanation is that the control is due to the antibiotic detected in the xylem. Hyphae are known to penetrate as deeply as 3 annual rings into the ray cells of the xylem

(Boyce, 1948). Once absorbed from the xylem, the antibiotic could be transported to other parts of the mycelium.

No matter where the antibiotic contacts the fungus hyphae, elimination of stem and branch infections above the site of application as reported by Moss is of high practical importance and undoubtedly due to movement of enough cycloheximide to cause death of the fungus. Even if there is no significant reserve in a tree following complete elimination of infection, it is known that periods of 10 to 15 years usually elapse before new infections develop sufficiently to cause appreciable damage (Buchanan, 1938; Childs and Kimmey, 1938; Lachmund, 1934.

Summary

The antifungal antibiotic cycloheximide (Acti-dione) is absorbed by, persists in, and is translocated upward in pole-size western white pine. The antibiotic persists for at least 2 years in the trunk bark of western white pine treated by the basal stem method. Cycloheximide was applied only to the lower trunk area and later recovered from needles of unsprayed branches. Movement was through the water-conducting elements, for the antibiotic could be detected in xylem tissue both at and above the site of application but was never detected in bark (phloem) tissue above the treated area of the trunk.

Cycloheximide was also found to be translocated to needles on untreated branches of eastern white pine.

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Natural Resources

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Review by Stephen H. Spurr
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As an outgrowth of an engineering extension lecture series given at the University of California, Los Angeles, in 1955, this summary of the natural resources has been put together by a group of 23 authors, all but 5 of whom are on the staff at one of that University's campuses. The orientation toward California's problems is indicated by the emphasis given to such items as fresh water from saline sources, the atmosphere, and air-pollution control. Nevertheless, the various authors range far and wide in treating their assigned topics.

The individual chapters vary a great deal in approach, coverage, and quality as seems to be inevitable when a book is compiled rather than composed. John Zivnuska's chapter on forestry is solid, factual, and unspectacular. Walter Taylor in writing on ecology, wildlife, and wilderness, repeats the familiar plea of nature preservationists. Hans Jenny on soils and Frits Went on photosynthesis restate their competent and familiar lectures on their specialties.

Despite the unevenness, the total effect of the book is favorable. The level striven for is high and often reached. Facts and figures are given to document both the status of our natural resources, and the problems and potentialities of their management. Even the professional in the natural resources field will find much that is stimulating and provocative, and will return to the book again and again. "Natural Resources" is one of the better books in the general conservation field.

The Effect of Drying Conditions and Certain Pretreatments on Seasoning Stain In California Redwood

BY
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CALIFORNIA REDWOOD, (*Sequoia sempervirens* (D. Don) Endl., is subject to a chemical stain in the surface zone of the lumber particularly in that cut from the outer part of the heartwood in butt logs. Generally, this material also has the highest moisture content of the tree, and is usually segregated as "sinker" stock. The content of extractives in this zone is also higher than elsewhere in the tree.[1] The stain is associated with migration of extractives during drying. As the moisture moves to the surface, it brings water-soluble extractives with it, which are deposited and concentrated in the zone of evaporation. Chemical changes of the extractives are also involved.

Furthermore, during drying, sticker marks become apparent as a result of contrast between light colored (or stain free) zones under the stickers and comparatively darker stained areas adjacent to the sticker zone. The extractives which would normally have been deposited at the sticker position, if free evaporation were possible, have migrated to the zone adjacent to the sticker, thus adding to the normal concentration of the extractives in that area as established by Anderson.[2]

The California Redwood Association[3] has reported that any condition which permits the moisture in the wood to dissolve large quantities of extractives before or after drying will lead to an increase in the amount of stain; therefore, low temperatures and humidities, and good circulation are recommended to reduce the stain. In

[1]Anonymous. Redwood—A report of fundamental investigations and related application studies for the Pacific Lumber Company, Institute of Paper Chemistry, 1937-45.

[2]Anderson, A. B. Report to the Redwood Research Committee, University of California Forest Products Laboratory, 1952.

[3]Anonymous. The drying of California redwood, California Redwood Association Research Report No. 1, 1949.

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one comparative industrial drying test (by S. Brown, California Redwood Seasoning Committee) of air drying followed by kiln drying from the green condition, the latter showed less stain. It has also been reported by Anderson[3] that a low pH of the wood sap will accentuate stain and that pH decreases on exposure to oxygen. Therefore, rapid conversion and sticking of the lumber are recommended.

Work was undertaken with three related objectives, studied concurrently: (1) to determine the effect of drying variables on seasoning stain with a view to recommending optimum drying procedures; (2) to study the extractives, their migration and behavior in relation to drying variables; and (3) to study the extractive materials from a chemical viewpoint in order to define their chemical structure and properties.

This paper is concerned largely with the effect of drying variables and pretreatments on stain occurrence.

Procedure

This study was conducted in two series. In the first, which was exploratory, 4/4 redwood boards were kiln-dried under a variety of conditions, while a concurrent study was made on techniques of evaluating stain, on the movement of extractives, and on the extractive components responsible for stain. All material for the runs was supplied in one shipment. In the second series, the techniques developed in the first stage were applied with more precise control of variables.

Series 1—the Exploratory Study

Material. Sinker segregation redwood (1,250 bd. ft.) cut from the outer zone of the heartwood of butt logs was ordered from a Eureka sawmill in cant sizes of 6 inches by 10-inch cross section in 20-ft. lengths. Specifications called for material to be cut from several freshly felled logs, and to be shipped to the Richmond laboratory without delay. Between the first and last kiln runs made with this material, five and one-half months elapsed.

[3]Op. cit.

On arrival at the Laboratory, the cants were first cut into 8-ft. lengths, and then side and end matched for use in all comparative drying studies. To facilitate shrinkage measurements and sectioning techniques, 25 5/4 boards were cut from the cants just before each run, and planed to 4/4 thickness before use. The remainder of the material was stored in cant form until required.

Drying conditions. Five kiln runs of lumber were made consecutively, and a control pile set out for air drying under cover on the laboratory grounds. Preliminary examination indicated that stain developed during the period of "free" water movement. Apparently this was the most critical time during drying. Consequently, among the kiln runs, only those conditions required to dry the wood down to 30 percent moisture content were varied. Drying from 30 percent wood moisture content down to a final eight percent was done uniformly at 180°F DBT (dry bulb temperature) with a 30 F° WBD (wet bulb depression) with conditioning treatment at 160°F and with 10°F for 15 hours at the conclusion of drying.

As temperature, humidity, and drying time were considered to be the most important drying variables, drying conditions were kept constant down to a moisture content of 30 percent for each kiln run to simplify the interpretation of the quantitative effects of the variables.

The kiln conditions used in the first stage of the run are shown in Table 1.

Stain evaluation. The evaluation of stain was made on the freshly planed surface of the boards at the conclusion of drying, both before and after conditioning. A planing depth of 1/16″ was adopted because preliminary tests showed that this depth always fell within the stained zones, and because it was similar to that used in trade practice.

After drying, freshly planed samples of the boards were subjected to high humidity (approximately 90 percent) at 80°F for 24 hours, and re-evaluated.

TABLE 1. Conditions for drying to a wood moisture content of 30 percent (Series 1).[1]

Kiln run no.	Dry bulb temperature	Wet bulb depression
	Degrees F	*Degrees F*
1	130	4
2	150	5
3	110	15
4	150	15
1A[2]	130	4

[1]All kiln drying was done in a small, experimental drying kiln with air velocity of 450 ft./min. through a 30"-wide pile so that the temperature drop would be minimized.

[2]Run No. 1A duplicated run No. 1 in order to determine the effect of the five-month storage period.

Evaluation was made by two methods: (1) visual estimation, in which the amount of stain and its intensity were given a numerical rating on a five-point scale; and (2) reflectance measurement in which a reflectometer measured the reflected light from the surface of the test boards. As the field of reflectance was small, 36 readings were taken on a grid system drawn on the surface of the board. Filters were also used to reduce the effect of board color (as distinct from stain) on the readings.

Extractive determination. Wafers for use in analysis of extracts were cut from two boards in each kiln run and from the material in the air drying pile, before drying began, at intervals during drying, at the end of drying, before conditioning, and after conditioning.

After being cut from the board, the wafers were cut into slices for determination of extractive migration. The thickness of slices were 3/32-inch from the surface (surface zone), 3/32-inch adjacent to the surface (intermediate zone), and 6/32-inch from the center of the wafer (central zone). The amount of extractives in each of these three zones was then determined gravimetrically.

Although it was believed that the initially water soluble components were responsible for the stain, water insoluble components were also determined. Gravimetric analysis was made of cold water soluble extracts and hot alcohol soluble extracts. Extraction with water was done first so that the alcohol extract did not contain water soluble material. Absorption analysis with visible light was also made on both extracts to measure their tinctorial power.

Results and Discussion—Series 1

Stain susceptibility of material. The average moisture content of the green cants varied from 134 to 176 percent, indicating that only a part of the material could be classified as sinker stock and, in general, would not be expected to stain excessively. Although a portion of the material supplied did stain, the stain was not severe in the first kiln charges dried, and the material was considered as moderately stain-susceptible. The color of the stain varied from a pale brown to a very dark brown, and was most pronounced in the summerwood portion of the growth ring. Stain was more severe on quarter-sawn boards than on those flat sawn, tended to occur in streaks, and was associated particularly with a large number of growth rings per inch. Contrast in stain was most pronounced at the sticker locations where stain was either light or absent under the stickers.

Migration of extractives during drying. Although results of both the gravimetric and spectro-photometric determinations on the extractives showed considerable variation, certain general trends were clear. In all the kiln runs, the total content of all extractive fractions tended to increase gradually in the surface zone during drying (Table 2). The central zone showed a progressive decrease in cold water soluable fractions and their tinctorial power, and an increase in the hot alcohol extractives and their tinctorial power (Table 3). It is clear that, in addition to the migration of the water soluble extractives to the

TABLE 2. Migration and behavior of extractive in a 4/4 redwood board during drying in kiln run No. 1.

Extractive component	Average moisture content of board at time of analysis (percent) 155	130	95	77	55	32	13	7
Surface zone[1]								
CW%	8.9	11.9	15.1	14.1	14.4	13.3	14.3	14.64
CW vis.	0.022	0.037	0.109	0.052	0.041	0.075	.....	0.063
HA%	6.48	6.33	6.33	5.86	6.71	7.57	9.33	10.27
HA vis.	0.252	0.284	0.267	0.306	0.286	0.358	0.416	0.484
Intermediate zone								
CW%	9.11	8.51	6.77	8.10	6.99	9.50	9.30	9.30
CW vis.	0.025	0.025	.....	0.0223	0.021	.....	0.0299	0.030
HA%	7.21	6.03	.....	.....	7.33	6.99	7.31	8.39
HA vis.	0.208	0.282	0.234	0.234	0.298	0.299	0.294	0.361
Central zone								
CW%	8.58	.....	7.49	6.74	6.62	5.80	5.30	4.92
CW vis.	0.031	0.030	0.022	0.022	0.031	0.050	.....	0.027
HA%	7.24	6.24	4.13	4.13	6.14	5.82	9.74	8.17
HA vis.	0.247	0.208	0.211	0.211	0.265	0.259	.....	0.389

[1]CW % = cold water extract; HA % = hot alcohol extract; CW vis. = cold water visible spectrum; HA vis. = hot alcohol visible spectrum.

surface zone, a change in the chemical nature of the extractives occurred simultaneously, reducing their solubility in water.

It was also noticeable that, for the lower the drying temperature, relatively more cold water soluble material and less hot alcohol soluble material were deposited at the surface (Table 3). This is to be expected if the temperature of drying converts a part of the water soluble fraction to a water insoluble form.

Effect of drying conditions on stain. The ratings of stain by the two different methods are shown in Table 4.

Both systems of rating were in agreement in that air drying followed by kiln drying (schedule No. 1) caused the least stain and that kiln run 1A caused the most. The reflectance evaluations indicate a relationship between stain and temperature of drying. The discrepancy between the ratings for kiln runs 2, 3, and 4 is due to two factors. First, the variation in stain among these three runs was slight, and second, errors were apparent in the reflectance measurement as a result of variations in the natural hue of the wood and the effect of widely differing reflectance values of the earlywood and latewood in the growth rings. Visual observation is therefore considered the more reliable of the two systems.

At the outset it was apparent that a major factor involved in stain production was the storage time of the material before drying; runs 1 and 1A had the same kiln schedule, but were carried out over a five and one-half month period. Consequently, it is not possible to state the effect of the drying variables on stain occurrence with any certainty especially since storage time appears to be a far more critical factor than the actual drying conditions within the range tested. However, the fact that there was little or no difference between the air dried material and that dried in kiln schedule 1 indicates that a wide variation in drying temperature and humidity does not substantially affect the stain occurrence, at least for material that is slight to moderately stain-susceptible. Further, if storage time in cant form had been sub-

stantial, it is apparent that kiln drying at any reasonable schedule (having regard for the prevention of other drying defects) will not obviate stain.

With reference to air drying, it should be pointed out that such drying at the California laboratory (particularly in a small pile) was substantially faster than that prevailing in the main redwood production centers. Therefore, it may be expected that, under very slow air drying conditions such as may exist in the northern coastal area of California, an effect similar to long-term green storage could be obtained.

In comparing the extractive behavior with stain it is seen that the amount of stain cannot be directly correlated with the total amount of extract nor with components of the extract within range of extractives covered. However, as the differences in stain were not particularly marked, except for kiln run 1A which was not analyzed, this is not surprising. In addition, the effect of storage time of the lumber

TABLE 3. Distribution of extractives in kiln-dried redwood[1]

Extractive component	Surface zone G.L.	Surface zone K.D.	Intermediate zone G.L.	Intermediate zone K.D.	Central zone G.L.	Central zone K.D.
			Run No. 1 (130°F–4°F–21 days)			
CW%	11.47	14.53	11.60	12.28	11.63	6.40
CW vis.	0.046	0.134	0.049	0.072	0.056	0.035
HA %	7.22	12.73	7.51	8.16	8.85	8.72
HA vis.	0.273	0.771	0.248	0.541	0.287	0.447
Tot. Ext.	18.69	27.26	19.11	20.44	20.48	15.12
			Run No. 2 (150°F–5°F–16 days)			
CW%	11.44	13.58	11.90	11.37	11.77	5.59
CW vis.	0.052	0.070	0.049	0.035	0.072	0.018
HA %	7.70	10.42	7.94	9.11	7.23	10.03
HA vis.	.....	0.508	.....	0.367	.....	0.369
Tot. Ext.	19.14	24.00	19.84	20.48	19.00	15.62
			Run No. 3 (110°F–15°F–14 days)			
CW%	10.52	16.23	11.70	10.09	11.56	7.21
CW vis.	0.084	0.117	0.104	0.078	0.100	0.058
HA %	8.48	8.48	8.31	7.35	8.20	7.81
HA vis.	0.331	0.330	0.334	0.328	0.306	0.327
Tot. Ext.	19.00	24.71	20.01	17.44	19.76	15.02
			Run No. 4 (150°F–15°F–12 days)			
CW%	15.58	16.62	12.15	6.56	11.03	4.18
CW vis.	0.108	0.187	0.135	0.033	0.109	0.031
HA %	.....	10.95	6.50	8.47	6.47	8.01
HA vis.	0.277	0.577	0.272	0.388	0.266	0.313
Tot. Ext.	.....	27.57	18.65	15.03	17.60	12.19
			Air-dried Run (78 days)			
CW%	11.47	18.33	11.60	13.22	11.63	7.85
CW vis.	0.047	0.123	0.049	0.087	0.056	0.07
HA %	7.20	9.01	7.55	8.46	8.91	8.08
HA vis.	0.273	0.361	0.248	0.326	0.237	0.36'
Tot. Ext.	18.67	27.34	19.15	21.68	20.54	15.93

[1]G.L. = green lumber; K.D = kiln dried; CW % = cold water extract; CW vis. = cold water visible spectrum; HA % = hot alcohol extract; HA vis. = hot alcohol visible spectrum.

was superimposed on the influence of kiln drying conditions on stain. The indications were that the stain is associated with both the cold water and hot alcohol soluble fractions.

Effect of exposure to high humidity. All surfaced boards showed an increase in intensity of stain when exposed to high humidity at the conclusion of drying. Also, the extractives on the surface of the boards appeared very hygroscopic, and tended to liquefy. The reflectance technique was used for this evaluation since measurements were taken on identical spots before and after exposure to give accurate comparisons. Results are shown in the following list of kiln runs, in order of increasing severity of staining: 1A, 2, 4, 3, 1, and the air dried material. It may be seen, from comparison with Table 4, that the effect of high humidity was generally greatest on those boards that showed the least amount of stain on removal from the kiln, and was least on material that showed the most stain after drying. This correlates, therefore, with the temperature of drying, i.e., elevated temperatures during drying reduce the tendency of the material to show increase in stain when exposed to high humidity, and probably correlates with the content of water soluble extractive in the surface zone.

TABLE 4. Listing of drying schedules in increasing order of stain development.

Visual observation	Reflectance measurement
Very slight stain	
Kiln run No. 1	Kiln run No. 1
Air drying	Air drying
Moderate stain	
Kiln run No. 2	Kiln run No. 3
Kiln run No. 4	Kiln run No. 4
Kiln run No. 3	Kiln run No. 2
Severe stain	
Kiln run No. 1A	Kiln run No. 1A

Series 2—the Controlled Study

Material and drying procedure. In this series, eight kiln runs and one air drying run were made. In the first six runs, the effect of drying variables on stain was studied; in the last two, the effect of long-term storage on stain was examined. In order to control the effect of log and cant storage time on stain development, freshly cut cants from recently felled trees (within one month) were shipped to the laboratory at intervals and dried immediately, two runs at a time, under widely differing drying conditions. Exact matching of material was possible within each pair of kiln runs.

For the last two runs, cants that had been cut six months provided material for evaluating the effect of storage time. Before the cants were converted into 4/4 boards, the outside ¼" was sawn off around the cant to avoid semi-dry material in the drying runs.

The kiln schedules were of a two stage type similar to that used in Series 1, except that drying from 30 percent moisture content downward was done uniformly at 180°F DBT, 50°F WBD, with one exception. All other drying conditions were similar to those used in Series 1. The schedules used are shown in Table 5.

Sticker stain studies. To determine whether it was possible to reduce the contrast of stain at the sticker location, various porous materials (blotting paper, fibrous insulation) were placed between the sticker and the board surface in selected test runs. In one case, blotting paper was fastened to the complete surface of a board in an attempt to obtain deposition of extractives in the blotting paper rather than on the surface zones of the board.

Pretreatments to prevent stain. Three types of pretreatment were tested as follows:

(a) Sodium azide (an enzyme inhibitor), which is proving successful in inhibiting brown stain in sugar pine, was applied to selected green boards and boards that had been dried for 1½ days to reduce the

TABLE 5. Conditions for drying to a wood moisture content of 30 percent (Series 2).

Matching of material	Kiln run number	DBT (°F)	WBD (°F)
Matched	5	110	20
	6	140	5
Matched	7	110	4
	8	140	40
Matched	9[1]	110	10
	10	110	10
Matched	11	140	5
	12	110	20

[1]Drying conditions changed to 140°F DBT, 40°F WBT, at 30 percent wood moisture content.

moisture content of the surface zone. Treatment was accomplished by dipping the boards in a solution containing 4 lbs. of Bazide plus 10 lbs. of Permatox S per 10 gallons of water.

(b) Water repellent preservative solutions (commercial preparations) were applied by dip treatment, for three minutes to green boards and to boards that had been dried for 1½ days to reduce moisture content in the surface zone. Although water repellents are not intended for this type of treatment, it was thought that they, or similar material, might alter the zone of deposition of the extractives.

(c) As heat appeared to have an effect on the nature of the extractives, selected boards were subjected to heating, prior to drying, by two different methods. Method 1 employed live saturated steam. Under the saturated conditions no appreciable drying took place. The treatments applied were: 225°F for 30 min.; 212°F for 10 min., 30 min., 2 hours, 7 hours, 15 hours; 180°F for 15 hours. Method 2 utilized high-frequency heating between platens at 212°F for 4 min. and 20 min.

Storage effects. As each kiln run was constructed, samples were taken and placed in cold room storage. In the last kiln run made (No. 12), these samples were included to determine the effect of storage on stain development in subsequent drying.

Stain evaluation and extractive determination. Stain was evaluated visually on a six point scale as in Series 1. The numerical rating system used in evaluating the amount of stain was as follows: 0 = none; 1 = very slight; 2 = slight; 3= moderate; 4 = severe; 5 = very severe. The boards for extract analysis were selected on the basis of high initial moisture content. Extract determinations were made as described in Series 1, at the beginning and end of each run. Extract distribution was also evaluated at the sticker zones where porous stickers were used for comparison with normal sticker zones. In addition, extractive evaluations were made on the heat-treated material.

Results and Discussion—Series 2

Stain susceptibility of material. The lumber obtained for Series 2 tests was generally more stain susceptible than that supplied for Series 1. Table 6 shows the relationships between extractive content, moisture content, and stain rating of sample boards from seven different cants dried under the various schedules used in Series 2.

There was some indication that total extractives, extractives deposited at the surface after drying, and the severity of stain tend to increase with increase of the original green moisture content of the lumber, but considerable variability exists in this relationship. The best correlations were between the total extractive and the extractive found in the surface after drying, and between the amount of extractive found in the surface zone and the stain rating although there were some deviations here. (Figs. 1, 2, and 3).

The fact that these relationships are apparent, although the data were pooled from all drying conditions, indicates that the amount of extractive dominates all other variables in determining the degree of staining.

TABLE 6. Relation between extractive content, green moisture content, and stain for Series 2 kiln-dried sample boards.

Total extractive content of green boards (percent)	Extractive content of surface zone after drying (percent)	Average stain rating	Original moisture content (percent)
38.70	50.68	3.40	232
25.18	39.62	2.25	243
24.95	44.70	3.63	230
20.53	30.24	2.57	175
16.83	26.19	1.46	155
14.96	25.21	2.56	204
11.97	12.51	0.50	46

TABLE 7. Average increase of extractives in surface zone after drying and conditioning[1].

Extractive component	Percent Increase based on original green content					
	KR5	KR6	KR7	KR8	KR9	KR10
CW %	101.5	87.5	73.6	134.0	103.5	86.0
CW vis.	113.0	102.0	103.0	98.0	123.0	150.0
HA %	23.0	39.5	37.0	10.5	1.0	23.0
HA vis.	40.0	84.0	80.0	55.0	35.0	3.5
Total	70.0	69.0	57.0	62.0	49.5	58.0

[1]KR = kiln run; CW % = cold water extract; CW vis. = cold water visible spectrum; HA % = hot alcohol extract; HA vis. = hot alcohol visible spectrum.

Behavior of extractives during drying. Table 7 shows the increase of extractives in the outer zone of the sample boards after kiln drying and conditioning. The increase is expressed as a percentage of the extractives in the original green board before drying.

In all runs, substantial increases of cold water soluble extractives occurred in the outer zone. The increase of water insoluble (hot alcohol soluble) extractive was less pronounced and more variable. In all cases a considerable increase in tinctorial power of cold water extractives also occurred; while the increase in the tinctorial power of the water insoluble extractive was less pronounced and more variable.

Comparing the extractive behavior within matched pairs of kiln runs, it may be

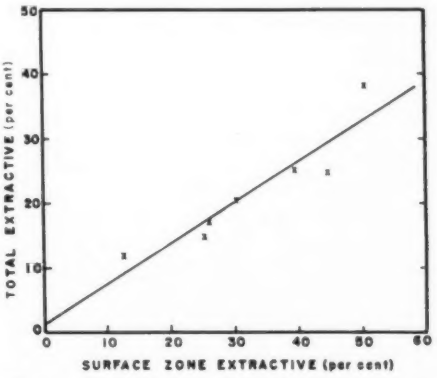

FIGURE 1. *Relation between total extractive content of green California redwood and the amount of extractive found in the surface zone of the boards after drying. (Results pooled from all kiln drying runs.)*

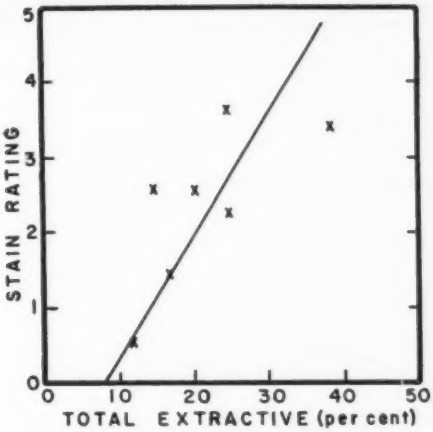

FIGURE 2. *Relation between total extractive content of green California redwood and the stain rating of the subsequently dried boards. (Results pooled from all kiln drying runs.)*

seen in runs 5 and 6, that although approximately the same percentage increase of total extractive occurred, the water insoluble extractive content was higher and the water soluble extractive lower in kiln run 6 sample boards. Comparing kiln runs 7 and 8, kiln run 7 boards also have a lower water soluble and higher water insoluble extractive than kiln run 8. Runs 6 and 7 were both made under high humidity (Table 5) although with a difference of 30 degrees F in dry bulb temperatures. It is apparent that high humidity tends to reduce the water soluble extractive components and increase the water insoluble extractives at both drying temperatures.

That the comparatively high initial temperature of 140°F does not per se, result in a high content of water insoluble extractives in the surface zone can be seen from kiln run 8. The indications are that the comparatively fast drying rate obtained in kiln run 8 as a result of the relatively high temperature and low humidity caused a large increase in water solubles and only a slight increase in water insolubles. This behavior denotes a dependent effect of time of temperature on conversion of water soluble to water insoluble extractives.

Air drying did not prevent a substantial increase of extractives in the surface zone. Air-dried material from one cant which was closely matched with material from another cant in kiln run 5 showed a slightly greater increase of extractives in the surface zone of the air-dried sample.

Consideration of runs 9 and 10, in which the drying conditions differed only after the specimens had reached fiber saturation point, shows that high final drying temperatures tend to reduce the percent of cold water soluble extractives and increase the percent of water insoluble ones. It is also of interest to note that the changes in tinctorial power of the extractives are not closely correlated with the changes in the amounts of extractive.

The conclusions drawn from the study of extractive behavior are:

(a) Under all drying conditions, substantial increases in amount of extractives and their tinctorial power occurred in the surface zones.

(b) High humidity conditions during the period of drying down to fiber saturation point tend to increase water insoluble extractives and decrease water soluble ex-

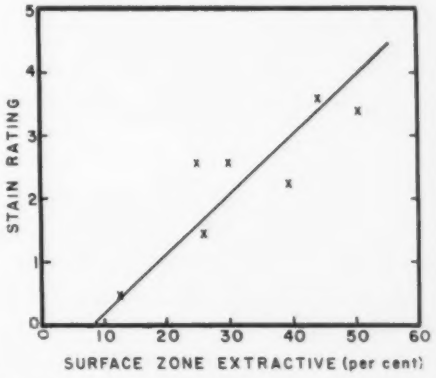

FIGURE 3. *Relation between the amount of extractive found in the surface zone of dried boards and their stain rating. (Results pooled from all kiln drying runs.)*

tractives, as compared with low humidity drying. This effect occurs at both drying temperatures.

(c) Under the fastest drying schedule used, the increased in water soluble extract was greatest and the increase in water insoluble extractive was one of the least in the surface zone.

(d) High drying temperatures in the later stage of drying tend to reduce the water soluble and increase the water insoluble extractive components.

Effect of drying conditions on stain. Table 8 shows the average stain rating for material dried under various conditions.

Apart from the material used in kiln runs 11 and 12, which contained low extractive content and was consequently not very stain susceptible, the material that was not pretreated developed sufficient stain to be of concern with respect to appearance. Disregarding pretreated material, some slight differences in staining intensity did occur between matched material dried under different conditions. Figure 4 shows the stain development in two matched boards dried under two different kiln schedules. To some extent the differences also represent the variability of the material although sample boards were matched closely.

Conditioning the boards at the conclu-

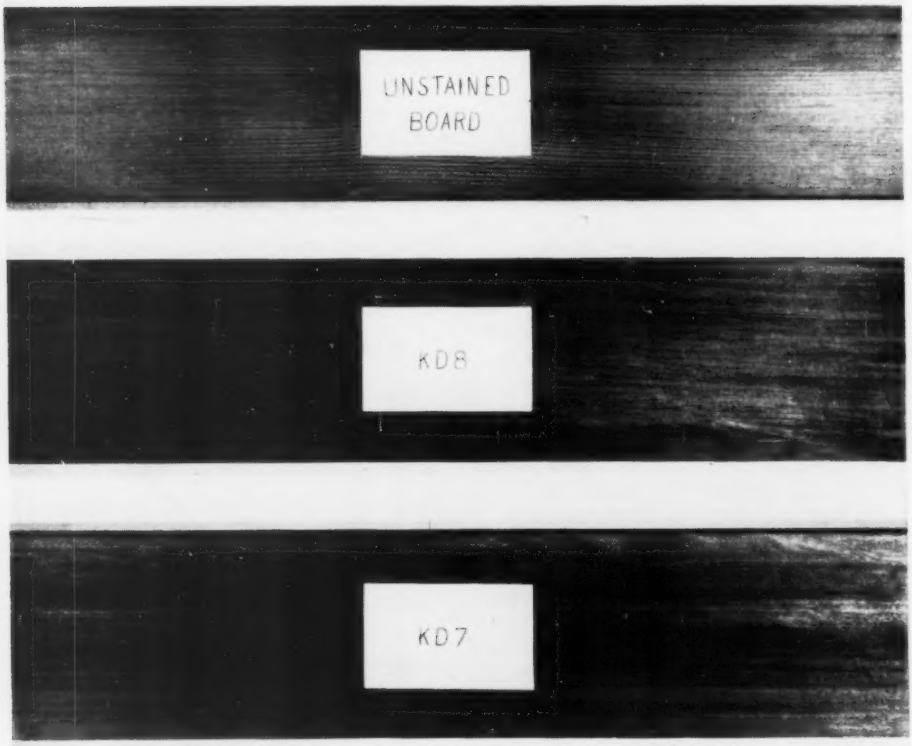

FIGURE 4. *Severe stain in two matched dried boards of California redwood which were kiln dried under very different schedules: KD7 = 110°F DBT and 4°F WBD; KD8 = 140°F DBT and 40°F WBD to 30 percent moisture content.*

TABLE 8. Numerical rating[1] of stain in boards after drying under various conditions.

Run number	Dried and conditioned	Dried, not conditioned	Presteamed, dried, and conditioned	Presteamed, dried, not conditioned	Water repellent pretreatment	Bazide pretreatment
Air drying plus final kiln drying	3.00	2.75	.....	0.00	.....	.....
5	2.92	3.00	1.00	0.33	2.50	2.33
6	3.00	3.00	0.50	0.00	2.80	2.40
7	2.60	2.50	1.33	.....	.....	.....
8	2.80	3.25	1.33	.....	.....	.....
9	2.38	1.40	.....	.....	.....	.....
10	2.13	2.00	0.00	.....	.....	.....
11	0.50	0.50				
12	0.50	0.50				

[1]Rating is based on a six-point scale (0-5) in which 0 indicates no stain and 5 indicates very severe stain.

sion of drying resulted in only slight and variable influence on stain. From this behavior it is concluded that, with relatively fresh material, the dominant factor influencing the amount of stain is the content of extractive in the lumber. The very different drying conditions, with respect to both temperature and humidity, did not substantially alter the degree of stain. In this connection, although the rating of the air-dried boards showed them to be as darkly stained as the material kiln dried from the green condition, they were lighter in color at the end of air drying and before final kiln drying.

The small differences in stain of the material among the various drying schedules cannot be satisfactorily explained by differences in the changes of extractive in the surface layer (Tables 7, 8). This is not surprising in view of variability of the stain and the extractive distribution within any particular board.

It is clear from the above results that little can be expected in the way of substantial reduction of stain by control of temperature and humidity in conventional kilns, at least within limits which would allow economical operation and not cause other defects in the lumber.

Effect on stain of exposure to high humidity after drying. Disregarding pretreated boards, all kiln-dried material showed substantial increases in the severity of staining after exposure to 90 percent relative humidity at 80°F for 24 hours. A numerical rating was applied to the change in stain intensity during exposure to high humidity, as follows: 0 = no change; 1 = very slight; 2 = slight; 3 = moderate; 4 = severe; and 5 = very severe. Table 9 shows the change in stain obtained.

The least change in stain was shown by the air-dried material, but differences among kiln-dried materials under different schedules were also very slight. Conditioning the material at the end of kiln drying apparently did not substantially influence the stain behavior of the boards when they were subsequently exposed to high humidity.

Reduction of intensity of sticker mark. Applying blotter pads ¼" thick under the stickers considerably reduced contrast in this area, and resulted in barely visible sticker marks. Although the porous pad absorbed some extractives, some were deposited under the sticker, and no substantial build-up of extractives occurred on either side of the sticker, as shown by

TABLE 9. Effect of high humidity on increase of stain[1] in dried boards.

Run number	Treatment of boards: Dried and conditioned	Dried, not conditioned	Presteamed, dried, and conditioned	Presteamed, dried, not conditioned	Dip treatments
AD	-----	0.00	-----	0.00	-----
5	3.25	3.25	0.33	0.33	2.67
6	3.25	3.25	0.50	0.50	2.00
7	4.83	3.75	1.67	-----	-----
8	3.44	3.62	1.67	-----	-----
9	3.40	3.50	-----	-----	-----
10	2.80	3.50	0.87	-----	-----
11	0.00	-----	-----	-----	-----
12	0.00	-----	-----	-----	-----

[1]Increase of stain is based on a six-point scale (0-5) in which 0 represents no change and 5 represents very severe change.

gravimetric extractive analysis. A similar effect was noted with the fibrous insulation-type sticker. Although there would be difficulties in instituting such a procedure on a commercial scale, it does suggest an approach to reduction of sticker stain.

In the board that had been completely covered with ¼-inch blotting pads stapled to the surface, differential shrinkage between the board and the blotting pad during drying resulted in wrinkling of the pad so that contact was not uniform. However, on the areas of contact, it was apparent that a large proportion of the extractives had moved into the blotting pad, resulting in less stain in those areas. It is therefore possible to reduce stain by creating another zone of evaporation of the water in contact with the wood surface.

Effect of storage. The results on the effect of cant storage on stain are still being evaluated; however, boards that had been kept in cold storage for three months before kiln drying showed an increase in intensity of staining as compared with those kiln dried immediately after sawing. This behavior confirms the effect found in Series 1 tests.

Effect of chemical treatment. Both the buffered sodium azide plus Permatox S and the water repellent preservatives had only a very slight effect on stain, whether the lumber was dipped green or surface dried (Table 8). If staining fractions are a result of action by enzymes, the delay period between sawing and dipping the boards could influence the results. Further, the stain susceptible green redwood contains very little void space because of the very high moisture content; consequently, little chemical applied in a dip treatment would be absorbed by green wood. In surface dry wood, similar difficulties of substantial absorption of chemicals applied by dip treatment also exist because of the relative impermeability of redwood.

Effect of preheating. A remarkable reduction of stain occurred in boards that were steamed before being dried (Table 8). In the better treatments, the amount of stain was reduced to the point of being barely visible or lacking (Fig. 5). Similarly, contrast in the sticker areas was not apparent in the heated boards. Presteaming of air-dried material before kiln drying did not show any marked effect, as might be expected. Presteaming of material before air drying and subsequent kiln drying, however, was effective. The least effect of presteaming was observed on green boards

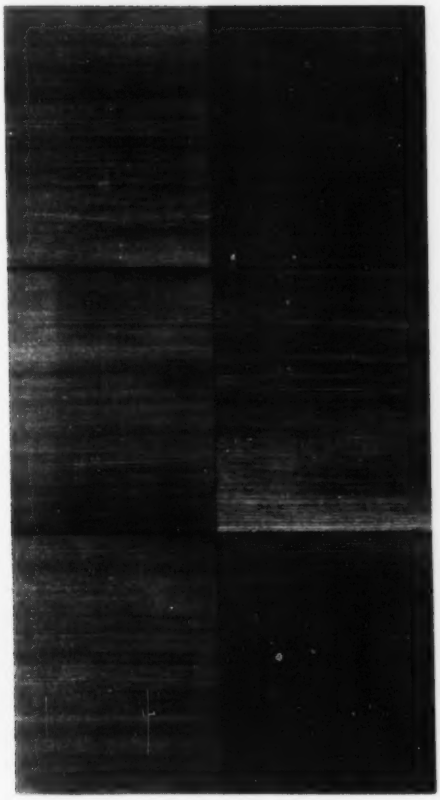

FIGURE 5. *Effect of pre-steaming on stain development in kiln-dried California redwood boards. Left: Steamed sections. Right: Unsteamed controls.*

that had been kept for three months in cold storage before drying. The effect of presteaming treatments on reducing or obviating stain appeared to be independent of the kiln-drying schedule.

The presteaming schedules that were most effective in reducing stain were 212° F for 15 hours, 7 hours, and 2 hours, and 225°F for 2 hours. Treatments at 212°F for 30 min. and 180°F for 15 hours, although having a marked effect, were not so effective as those for the longer heating periods.

High frequency heating at 212°F for 4 min. was the least effective of the heat treatments, whereas heating by this method for 20 minutes was equivalent in its effect to the steaming treatments at the shorter times.

Gravimetric and absorption analysis of extractives, which was conducted on wood after steaming and after drying, showed the following in comparison with wood not preheated: (a) Preheating of green wood tended to reduce the percentage of cold water soluble extractives deposited at the surface layer and to reduce light absorption in the visible spectrum (i.e., reduce tinctorial power) in the hot alcohol soluble and cold water soluble extractives. (b) The effect was more pronounced at the longer heating times. (c) There was some indication that the tinctorial power of the hot alcohol extractives decreased in the outer zone, although the content of hot alcohol extractives increased.

The behavior of the extractives during drying in a typical preheated board in comparison with that in a matched, unsteamed board is shown in Table 10.

The content of cold water soluble extractives in the surface zones of preheated boards was considerably reduced at the end of drying as compared with that in boards not heat treated. However, the total of such extractives and the total of all extractives exceeded those in untreated boards (used in other parts of the study) which did not show substantial stain. In this connection the total extractives and the cold water extractives in one of the boards selected for heat treatment were the highest (i.e., 33.6 percent and 18.2 percent, respectively) of any board analyzed during the complete investigation. Material from this board steamed for seven hours at 212°F did not show any substantial stain, but when dried without preheating, the stain was as severe as any found in the series.

It is apparent that the preheating treatment affected some components of the hot alcohol extractives and probably some of the cold water extractives which are primarily responsible for the tinctorial power

TABLE 10. Effect of preheating at 212° F for 7 hours on extract behavior in surface zones before and after kiln drying.

	Green control	Green, after steaming	Dried control, no preheating	Dried, preheated
CW %	9.51	9.94	17.86	15.15
CW vis.	0.0206	0.0122	0.0569	0.0237
HA %	7.97	7.94	10.94	8.46
HA vis.	0.3639	0.4191	0.3655	0.1857
Total extract %	17.48	17.88	28.80	23.61

of the extractives. Work is continuing to isolate these fractions and determine their sensitivity to heat.

Exposure of the presteamed and dried specimens to high humidity resulted in very little or no increase in the amount of stain (Table 9). In some cases a very pale brown color was observed on the surface of the sample. But in no case did any presteamed board show as much stain on exposure to high humidity as the lightest stained boards containing less than 15 percent of extractives.

Examination of cross sections cut from boards that were presteamed and dried, and then exposed to high humidity, showed that extractives were present in the surface zone of the sections and were somewhat hygroscopic, as expected from the chemical analysis (Fig. 6). However, the color of the hygroscopic extractive was very pale amber throughout the full depth of its occurrence, in contrast to the very dark brown color of the extractives that occurred in sections which were not presteamed. This behavior indicates the possibility of a specfic effect of heat on the fractions within the extractives that are responsible for staining power, as distinct from the effect of the reduced amount of extractives in the surface zone.

Although no substantial staining of the preheated boards occurred on exposure to high humidity, it is yet too early to say

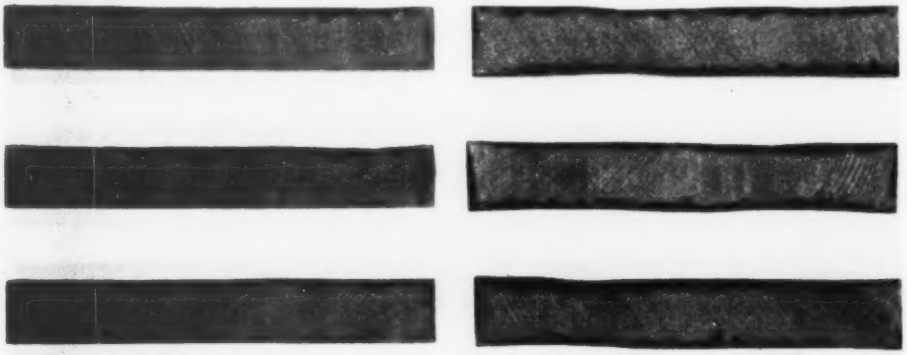

FIGURE 6. *Showing presence of extractives in surface zones of wafers cut from kiln-dried California redwood boards which were subsequently exposed to high humidity. Left: Steamed sections. Right: Unsteamed sections. Extractives are present in the surface zones of the presteamed boards, but are non-staining.*

whether stain would eventually develop under conditions of service, e.g., as unpainted siding. Weatherometer and exposure tests are planned, to evaluate the permanence of the stain reduction, together with more intensive chemical investigations.

Although yet to be fully evaluated, preheating appears to be a promising method of reducing or obviating stain. The cost of an operation on higher qualities of sinker stock segregation is reasonable, control is not difficult using saturated steam at atmospheric pressure, and the necessary duration of steaming is of a practical length. In this connection, it is not advisable that the duration of steaming be extended beyond six hours because of increased tendency of the steamed material to collapse during subsequent drying.

Conclusions

1. Chemical stain in redwood occurred under all drying conditions used in this study. The intensity and extent of stain were most affected by the total extractive content of the green board, which was also associated with the green moisture content of the lumber, next by the length of storage of the green cants or lumber, and least by the actual drying conditions.

2. The period of storage of green cants (or lumber) strongly affects the intensity of stain which develops in subsequent drying. A storage time of 5-½ months for green cants resulted in development of severe stain in material which contained only moderate amounts of extractive and which showed only slight stain when dried within a week after sawing.

It is believed that slow air drying would result in similar increase of staining intensity upon subsequent drying.

The storage effect on stain production could be expected to be more pronounced on material which contains low quantities of extractives since material with a high content of extractives will stain in any case.

3. The depth from the board surface of the stained zone, and its thickness, were not measurably affected by the drying schedules used, within the limits of the thickness of the sections evaluated.

4. Variation of drying method or drying schedule within the limits of good drying procedure does not provide a means of controlling stain in air or kiln drying.

The extent and intensity of stain developed in the material during drying were only partially affected by the drying conditions. Air drying or kiln drying at low temperatures and low humidities tended to reduce slightly the intensity of staining in samples examined immediately after drying. This effect was more pronounced on material with low total amounts of extractives. In material with medium and high content of extractives, substantial differences were not apparent among different kiln-drying conditions, although the air-dried material showed least intense stain immediately after drying.

5. Under all drying conditions, substantial increases of extractives and their tinctorial power occurred in the surface zones. High humidity during drying to fiber saturation point tended to increase water insoluble extractives and decrease water soluble extractives, as compared with low humidity drying. This effect occurs at both drying temperatures. Under the fastest drying kiln schedule used, the increase in water soluble extractive was greatest, and the increase in water insoluble extractive one of the least, in the surface zone.

High drying temperatures applied to the wood below the fiber saturation point tend to reduce the water soluble and to increase the water insoluble extractions.

6. The extractives deposited in the surface were hygroscopic. Stained boards after drying were found to be sensitive to high humidity with respect to darkening of the stain and accentuation of sticker marks. The increase in stain which developed was essentially permanent and persisted after subsequent redrying. The extent of this effect varied with the drying conditions used.

Boards dried under conditions which re-

sulted in the least intensive stain immediately at the conclusion of drying showed the greatest amount of increase in intensity of stain when exposed to high humidity. Such differences of stain did result from drying method or schedule were reduced after exposure of the board to high humidity, the net effect being that drying conditions only partially altered the final intensity. Gravametric determination of extractives indicated that material containing the highest content of water soluble material in the surface zone was affected most by subsequent high humidity.

7. Contrast in color at the sticker area in stain susceptible redwood can be minimized by the use of porous material between the sticker and the lumber, so that moisture can move from the surface zone under the sticker without impedance.

8. Heat treatment of the lumber prior to both air and kiln drying markedly reduced the amount of stain that occurred in subsequent drying. The treatment was effective for all kiln schedules tried and for air drying. Furthermore, the heat treated material did not show substantial darkening when exposed to short-term high humidity after drying, which indicates that staining of the lumber during outdoor exposure may be considerably reduced. Weatherometer and long term exposure tests of the heat treated material are necessary to determine the permanence of the effect. There was some indication that heat treatment was less effective on green material that had been kept in storage for three months before heating and drying. These effects are being investigated further.

Chemical analysis of heat treated material showed that, although the treatment caused some reduction in the deposition of water soluble extractives in the surface zone, in subsequent drying the main effect was a reduction in the tinctorial power of components in the water soluble and alcohol soluble extractives. Further investigation of the nature of these tinctorial materials is proceeding.

Although further work is necessary to evaluate the limitations and potentialities of the method, heat treatment of stain susceptible redwood shows promise of being an effective means of reducing stain and is believed to be worthy of commercial trials.

Regularity in Distribution of Supernumerary Needles on the Terminal Growth of Young Jack Pine Trees

BY
A. W. GHENT
J. B. THOMAS

ALTHOUGH number of needles per fascicle is characteristically constant for many pine species, fascicles with exceptional needle numbers are not unusual. This paper relates the occurrence of 3-needled fascicles in jack pine (*Pinus banksiana* Lamb.), a species characterized by 2-needled fascicles, to position, shoot type, season, and age of the trees.

Position on Shoot

Figure 1 shows the terminal shoot of a young jack pine with 3-needled fascicles localized in the areas immediately below the terminal buds of the leader, primary lateral branches, and internodal branches, and the junction of the leader and the internodal branches. The excess of 3-needled fascicles below the apex of the leader as compared with their occurrence below the apices of internodal and primary lateral branches is not invariable. The reverse may occur.

Variation Between Years

Examination of the incidence of supernumerary needles at three successive nodes, 1956 to 1958, of 61 trees showed a variation from year to year. Production of 3-needled fascicles in 1957 represented a weakly significant increase over that in 1956, and their production in 1958 represented a further and strongly significant increase from 1957. This comparison is set out in Table 1, along with the results of appropriate 2×2 contingency tests between comparable areas at the nodes. For instance, between the last 0.5 inch of the 1958 leaders (19.1 percent) and the last 0.5 inch of the 1957[1] leaders (11.8 percent), a significance beyond the .001 level is attained. The interpretation of this increase is confounded by possible differences in the influence of the weather during these three years and unquestionable changes in the height, age, and vigor of these young trees during this period.

Lammas Shoots

During a study of lammas shoot growth on jack pine, Thomas[2] gained the impression that 3-needled fascicles occurred in unusually high frequency on these shoots. Data

[1]Data for the most apical two inches of the 1957 leaders from these 61 trees were lumped with earlier data in preparation of Fig. 1, so that the incidences of 3-needled fascicles given in Fig. 1 and Table 1 are similar but not identical.

[2]Thomas, J. B. The production of lammas shoots on jack pine in Ontario. For. Chron. 34:307-309. 1958.

Contribution No. 597, Forest Biology Division, Research Branch, Department of Agriculture, Ottawa, Canada. The senior author is now with the Department of Zoology, The University of Chicago. The junior author is stationed at the Forest Insect Laboratory, Sault Ste. Marie, Ontario. Manuscript received Nov. 24, 1959.

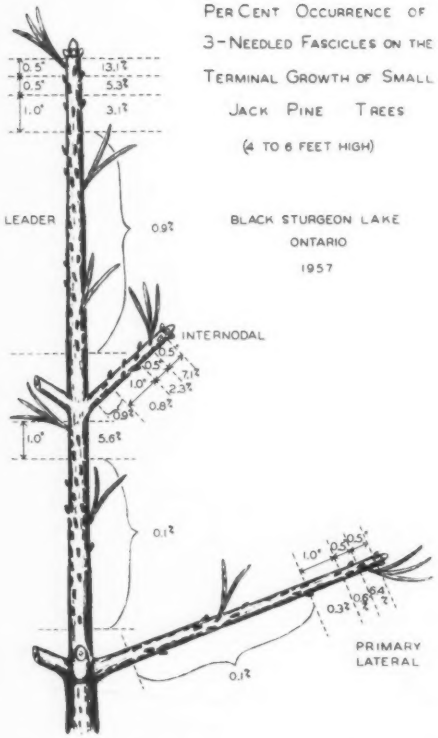

FIGURE 1. *Percent occurrence of 3-needled fascicles on various areas of the terminal growth of young jack pine trees. Basis: upper 2 inches of leader, 101 trees, 3200 fascicles; remainder of leader, 33 trees, 3700 fascicles; internodals, 44 samples, 1500 fascicles; primary laterals, 66 samples, 2100 fascicles.*

were gathered during the 1958 field season to permit a test of this impression. The incidence of 3-needled fascicles among *all* needle fascicles on the lammas shoots was tested against their incidence on only the *most apical* half-inch (i.e., the area of highest incidence) on the normal shoots (Table 2). Data for leaders and primary laterals were lumped in both groups, since in each case these within-group differences proved non-significant. The difference between the 42 percent incidence of 3-needled fascicles among all fascicles on the lammas shoots, and the 22 percent incidence observed at the tips of normal shoots, is strongly significant. Restriction of data for normal shoots to their most apical half-inch is a conservative factor in a test that nonetheless indicates a highly significant increase in the production of 3-needled fascicles on lammas shoots.

Variation with Age

During 1959, a check of 31 terminal branches at the approximate center of the upper crowns in ten trees from 105 to 115 years of age failed to disclose a single 3-needled group. In a 35-year-old stand nearby it was found that true leaders could still be readily distinguished, and that about 4 percent of the fascicles on the most apical half-inch of the 1958 leaders of a sample of 18 trees were 3-needled.

The 61 trees on which Table 1 is based were not more than 10 years of age. On the most apical half-inch of their 1958 leaders, however, 19.1 percent of the fascicles were 3-needled. Taking together the evidence of an increase in the production of supernumerary needles during early life given in Table 1, with the evidence of a later decline based on the 35-year-old and 105- to 115-year-old trees examined in 1959, the production of supernumerary needles appears to reach a maximum at an early age.

Discussion

Red pine (*P. resinosa* Ait.) and Scots pine (*P. sylvestris* L.) also frequently bear 3-needled fascicles on the most apical half-inch of the leaders of young trees.

Doak,[3] in a detailed study of the evolution of *Pinus*, records the production of 3-needled fascicles experimentally in an ordinarily 2-needled species, but does not speculate on the mechanism that produced the increase in needle numbers. The detailed observations we have made on the terminal

[3]Doak, C. C. Evolution of foliar types, dwarf shoots, and cone scales of *Pinus*. Univ. Ill. Bull. 32:1-106.

TABLE 1. Comparison of production of 3-needled fascicles on the leaders of 61 small jack pines on which counts could be made at the three successive nodes.

Year	Distance below shoot apex (inches)	Incidence of 3-needled fascicles	Significance of increase compared with 1-yr. previous	Significance of increase compared with 2-yrs. previous
1958	0.0–0.5	213/1115 = 19.1%	<.001	<.001
	0.5–1.0	47/460 = 10.2%	Not Sig.	<.001
	1.0–2.0	57/729 = 7.8%	<.01	<.001
1957	0.0–0.5	114/962 = 11.8%	<.01	
	0.5–1.0	27/397 = 6.8%	Not Sig.	
	1.0–2.0	23/651 = 3.5%	Not Sig.	
1956	0.0–0.5	59/789 = 7.5%		
	0.5–1.0	18/431 = 4.2%		
	1.0–2.0	17/740 = 2.3%		

TABLE 2. Comparison of all fascicles from 39 samples of 1958 lammas shoots with fascicles from the most apical 0.5 inch only of 98 samples of 1958 normal shoots.

	Needle Number 3	2	
Lammas shoots	369 (256.2)	514 (626.8)	883
Normal shoots	399 (511.8)	1365 (1252.2)	1764
	768	1879	2647

Total chi-square = 104.05 with 1 d. of f. p = <<.001

growth of young jack pine suggests that the causative factors in the production of supernumerary needles are evidently to be sought in the most distal areas of these young jack pine shoots. The pattern of distribution of supernumerary needles suggests this working hypothesis: that their occurrence is governed by the apical production of some hormone-like substance that becomes concentrated wherever the rate of shoot elongation declines. The portion of the main stem immediately below the internodal branches may represent such an area during the period while these internodal branches are being differentiated.

Multiple Regression Analysis of Radial Growth in Individual Trees

BY
HAROLD C. FRITTS

A PRIMARY DIFFICULTY encountered in studies of tree growth is that of subjecting a mature tree to controlled environmental conditions. A more practical approach is to measure and analyze the variations in growth of individual trees and the concurrent variations in several environmental factors. The simple regression and correlation of only one factor with growth may be useful where a particular factor is the primary control, but where several factors may be limiting at different times, or where they may interact, a multiple regression analysis is more appropriate.

This multiple regression approach to problems in tree growth is now more practical due to both the increased availability of card programs for electronic computors (Grosenbaugh 1958) and the development of a precise instrument for recording changes in tree radius (Fritts and Fritts 1955). The dendrograph can be used to obtain continuous records of changes in a tree radius which can be read to 0.0001 of an inch. These records may then be converted to values of daily maximum size, and daily growth computed by determining the increase beyond the highest maximum previously reached. Obviously, such growth results from hydration of plant tissues as well as assimilation and cambial activity.

Even though measurements along a single radius are not a good measure of total circumference growth, the relative day-to-day values are essentially proportional. Thus the relationships computed from the measured radius are assumed to be characteristic for the other radii at the same level in the tree.

For each day, the growth values of the individual trees, as well as the values of the appropriate environmental factors, can be punched on a single computing card. The resulting cards can then be fed into an electronic computor and the elements of a multiple regression calculated for the growth of each tree (Fisher 1954, Grosenbaugh 1958, and Snedecor 1956).

If interpretation of such a regression analysis of growth is to be successful, it must meet two conditions: (1) There must be a sufficient number of observations to demonstrate statistical significance in the data at hand, and (2) the results must be interpretable in terms of the processes and environment of the individual organism. Since with the dendrograph one can obtain continuous growth measurements, it is possible to extract from 80 to 140 daily obser-

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The author, formerly Assistant Professor of Botany, Eastern Illinois University, Charleston, Illinois, is now Assistant Professor in the Laboratory of Tree Ring Research, University of Arizona, Tucson. The study has been made posible by the help of the Ohio State Statistical Laboratory and the University of Illinois Statisitcal Service. The author is also indebted to the American Philosophical Society (Johnson Fund), the Ohio State University Development Fund, and the Illinois Academy of Science for grants to various phases of the study; and to Kenneth E. Damann and Francis H. Craig for use of the study area. Manuscript received Nov. 2, 1959.

vations on one tree in a single growing season. Observations on the independent variables can be obtained by recording the micro-environmental factors and calculating daily values for these. Thus a large number of observations can be collected without introducing variability due to grouping of measurements made on a number of trees or made during other growing seasons. It would appear that such an analysis of data for the individual tree may be valid and useful in analyzing the complex growth-environmental relationship. It is the purpose of this paper to investigate the feasibility of this approach.

Previous Investigations

With the development of the improved dendrograph (Fritts and Fritts 1955) a a study was initiated on growth of American beech (*Fagus grandifolia* Ehrh.) in central Ohio (Fritts 1956b, 1958). Dendrographs were placed on six beech trees growing on sites grading from well drained to poorly drained. Measurements of daily radial growth were made during the growing seasons of 1954 and 1955. The daily growth of the six trees during both years was treated as one unit and analyzed in terms of 14 variables. Three of these variables—day number, its square, and its cube —were included to allow the elimination of long-term seasonal patterns. Maximum and minimum temperatures and their squares were used so that a parabola could be fitted to these data. Only straight lines were fitted to the data for growth on the other environmental variables. All partial regression coefficients except those for growth on minimum temperature proved to be significantly different from zero (at the 1 percent level). The regressions for growth on each independent environmental variable were used to estimate the contribution of each factor to the growth of these trees during the two years studied.

Although the above treatment using a number of trees as a single group (Fritts 1958) was helpful in analyzing the factors controlling growth of the beech forest, it did not provide information on differential effects of the micro-environments of the individual trees and of yearly climatic regimes. Only straight lines were fitted to several factors for which more flexible parabolas may have been more suitable. However, the appropriate program, money, and time needed were not available and further statistical computations were not then attempted.

During 1957 a second study was initiated in a ravine oak-hickory forest in central Illinois (Fritts 1959). Dendrographic measurements were made on two white oaks (*Quercus alba* L.) and a sugar maple (*Acer saccharum* Marsh.), and the growth of each individual tree was analyzed by multiple regression techniques.

A striking difference in the temperature response between white oak and sugar maple was related to differences in ecological amplitudes and distribution of the two species. It was pointed out that inferences on the basis of measurements taken from a few species were not conclusive, but since one white oak and the sugar maple were growing side by side in very similar environments, the striking difference in their temperature response was most likely due to differences in heredity. The second white oak, growing on a more exposed site and in a very different environment, had a growth-maximum temperature curve very similar to that of the first white oak.

It appeared from these two studies that multiple regression analysis of daily growth of individual trees rather than of a group might be a more useful approach because of the possibility of evaluating differences due to tree condition, site factors, and individual heredity. The appropriateness of such consideration of the individual in its local environment is brought out by Mason and Langenheim (1957) and Glock (1955).

Methods and Results

Two investigations are presented in this paper. In the first, the 1954-55 data for beech (Fritts 1958) were reanalyzed in terms of the individual trees for separate

TABLE 1. Characteristics of six beech trees studied during 1954-1955.

Tree	Dbh (inches)	Crown area (sq. ft.)	Index of relative leaf area	Index of relative competition	Forest association	Soil drainage
1	20.5	1,[illegible]0	40	42	Beech-maple	Well drained
2	21.3	1,300	39	52	Beech-maple	Well drained
3	20.0	940	38	44	Beech-elm	Imperfectly drained
4	20.2	900	18	35	Beech-elm	Imperfectly drained
5	23.7	810	28	49	Swamp forest	Poorly drained
6	19.0	800	24	14	Swamp forest	Poorly drained

growing seasons, using the program K-14[1] designed for the Iliac computor.

In the second study, dendrographs were mounted on six trees (including two trees of three species) in the same Illinois ravine forest previously studied by Fritts (1959). The radial changes were measured during the early spring season of 1958 along with several environmental variables. The data for each tree were analyzed by graphical regression techniques.

Study 1: variations in growth among individuals of beech—growing seasons of 1954 and 1955. The six beech trees used in this study were growing in a 2.72-acre study area located in a forest tract 10 miles east of Columbus, Ohio. The trees all had approximately the same bole size and were located along a transect grading from a well drained to a poorly drained site (Table 1). The forest areas on the well drained sites are dominated by beech and sugar maple, and with a difference in relief of only six feet the forest changes to beech-elm on the 1-3 percent slopes and to swamp forest in the poorly drained depressions (Fritts 1956b, and Fritts and Holowaychuk 1959). The crown area projection for each tree was measured and an index of relative leaf area was obtained (Table 1) by multiplying crown area by crown thickness and relative density. An index to relative root competition was also obtained by measuring the relative overlap of spheres of influence from adjacent trees (Fritts 1956b).

Wind, relative humidity, and sunshine were recorded at the Columbus Airport (U. S. Weather Bureau 1954 and 1955), which was four miles from the study area and on similar terrain. Soil moisture was measured by a Colman meter, using three fiberglas gypsum blocks placed at a six-inch depth around each tree. The temperatures and rainfall were recorded at a weather station located in an open field on a level area 1,200 feet from the study trees. The temperature measurements were made by means of a thermograph housed in a louvered shelter five feet from ground level. Since only one thermograph was available, this location was considered best, as it would give results comparable to Weather Bureau data. It was thought that the temperatures would be correlated with (though not equivalent to) temperatures in the forest. A later check on the relation between open field temperatures and those in an Illinois forest at the five-foot level (the level of growth measurement) showed that maximum temperatures in the two locations were correlated with coefficients ranging from .90 to .99. However, linear regressions between the two locations demonstrated that maximum forest temperatures were commonly 2 to 7°F lower once the forest canopy was completely closed.

Daily growth was analyzed in terms of 21 variables (column 1, Table 2) which were the same as those used in the earlier

[1]The program is described in "Library Routines of the Digital Computor Laboratory of the University of Illinois."

study, with the following exceptions: Minimum temperature was not included, as it appeared non-significant in the earlier treatment (Fritts 1958). Percent sun of two and three days previous to growth were added, as well as squares of soil moisture at a six-inch depth, daily precipitation, average wind, relative humidity, percent sun, and percent sun of previous day. The study period was the same, from May 1 to August 20, for both years.

The adjusted indices of multiple determination (Table 2) indicate that there is a direct relationship between the percentage of variance accounted for and long-term factors, such as relative leaf area and competition from neighboring trees. For example, tree 1, which had a large crown, and which was surrounded on all sides by mature trees, had the highest index of multiple determination. The lowest index of multiple determination was obtained for tree 4, which had a very thin and small crown, and was in an area of relatively low competition. Similar but intermediate relationships are apparent in the other trees.

The partial regression coefficients in each analysis were tested for significance from

TABLE 2. Multiple correlation coefficients and significance levels of partial regression coefficients for growth of six beech trees during 1954 and 1955.

Independent variable		Year 1954						Year 1955					
		Beech-maple site		Beech-elm site		Swamp forest site		Beech-maple site		Beech-elm site		Swamp forest site	
		(1)[1]	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Soil	X	.01	.01	.05	.....	.....	.10	.....	.....	.....	.....	.05	.....
moist.	X^2	.01	.05	.10	.....	.....	.10	.....	.....	.....	.....	.05	.10
Max.	X	.....	.10	.....	.01	.10	.....	.05	.05	.10	.05	.05	.....
temp.	X^2	.....	.....	.....	.05	.....	.....	.10	.10	.....	.....	.10	.....
Daily	X	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
precip.	X^2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	X	.....	.10	.01	.05	.10	.....	.....	.10	.....	.....	.....	.....
wind	X^2	.10	.05	.01	.05	.05	.....	.....	.....	.....	.....	.....	.....
Humid.	X	.05	.05	.....	.....	.01	.05	.....	.05	.05	.....	.....	.....
at 1300	X^2	.....	.10	.....	.....	.05	.05	.10	.05	.01	.05	.....	.....
Percent	X	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.10	.....
sun	X^2	.10	.....	.10	.10	.....	.....	.....	.....	.....	.....	.....	.....
Percent sun	X	.05	.05	.....	.....	.....	.10	.05	.01	.01	.05	.01	.05
1d. prev.	X^2	.05	.05	.....	.....	.....	.....	.10	.05	.01	.10	.05	.10
Percent sun 2d. prev.	X	.05	.....	.10	.....	.05	.....	.....	.10	.05	.10	.....	.....
Percent sun 3d. prev.	X	.....	.10	.....	.....	.05	.....	.....	.....	.....	.....	.....	.....
Day of	X	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
growth	X^2	.01	.01	.01	.05	.01	.01	.01	.01	.01	.01	.01	.01
	X^3	.01	.01	.01	.10	.01	.01	.01	.05	.01	.01	.01	.01
Index of multiple determination		.801	.784	.706	.664	.770	.773	.804	.762	.828	.693	.793	.746
Index of multiple correlation		.895	.885	.840	.815	.878	.879	.896	.873	.910	.832	.890	.864
Standard error of estimate		.020	.020	.023	.021	.019	.018	.028	.031	.025	.028	.024	.024

[1] Numerals in parentheses refer to tree numbers.

TABLE 3. Comparative Weather Bureau data for Columbus Airport and soil moisture for two well drained and two poorly drained sites in beech study area.

	Mean maximum temp. (departure from normal)	Number of days of max. temp. 90°F or over	Mean percent sunshine (departure from normal)	Average available soil moisture at six-inch depth (percent volume)	
				Well-drained sites	Poorly-drained sites
1954					
May	−3.2	1	−1	16.4	13.5
June	+2.5	10	+5	13.0	11.9
July	+1.1	11	+12	7.0	9.2
Aug.	−1.7	4	−2	8.1[1]	9.5[1]
1955					
May	+3.5	0	+4	16.1	13.0
June	−3.3	1	−4	14.0	11.1
July	+4.5	22	−4	8.4	7.4
Aug.	+5.5	17	+7	2.2[1]	3.1[1]

[1]August 1-20 only.

zero by means of a t-test. Those values with a less than .01, .05, and .10 probability (b = zero) are indicated in Table 2. Such a test of individual regression coefficients is primarily designed to evaluate the slope of a linear relationship. When applied as in this study to a curvilinear relationship, its significance is less meaningful. It is believed that the test does afford some indication of those factors which were most influential in controlling the growth of the tree; however, it does not accurately measure the significance of the relationship.

Striking dissimilarities in significance of the coefficients are apparent between the two years (Table 2). This is not surprising, since different factors would be expected to be limiting under different climatic regimes.

Comparative Weather Bureau data (U. S. Weather Bureau 1954 and 1955) and soil moisture values for the two growing seasons are summarized in Table 3. May of 1954 was characterized by cooler than normal weather, while June and July were unusually sunny with above normal temperatures. During late June and early July, low rainfall and above normal sunshine and temperatures caused soil moisture on the well drained sites to decline rapidly. Rains and more normal temperatures starting about mid-July brought more moist and cloudy conditions for the rest of the growing season. In 1955 May temperatures as well as those in July and August were above normal, but sunshine and rainfall remained about average until late July. Soil moisture remained relatively high until late July when it began to decline markedly, especially in the poorly drained site around tree 5 where roots were shallow and competition was high. During August, values approached the wilting percent around all six trees.

Thus during the 1954 season of early drought, soil moisture in the better drained sites (trees 1, 2, and 3) and average wind exhibited the more significant growth-environmental coefficients. In 1955, with a more moist and less sunny early season and dry late season, the growth-sunshine coefficients were more significant. The soil moisture coefficients were more significant for the poorly drained trees (5 and 6). The effect of climatic regimes is more fully considered in the discussion of the respective curves.

The lower left curves in Figure 1 illustrate the growth-soil moisture relationships found in the six trees. Most curves show

low growth rates with both high and low soil moisture. During the 1954 season the reduction of growth at low moisture values is most apparent, especially in the trees on the better drained sites. In 1955 this relation is less pronounced and growth reduction at high values is more marked, especially for those trees in the poorly-drained sites. Thus low growth occurs, as would be expected, either when available soil moisture is directly limiting or when high moisture causes conditions of poor aeration to become limiting.

The effects of high versus low compe-

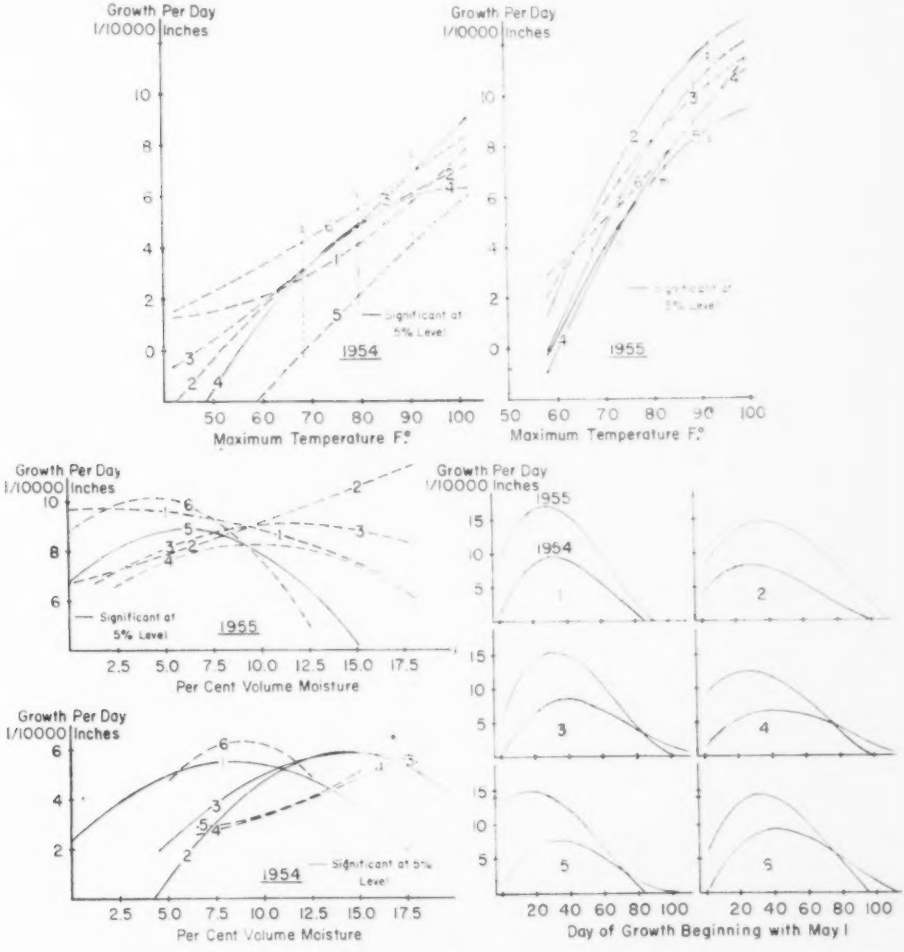

FIGURE 1. *The relation of daily radial growth of six beech trees on daily maximum temperature, daily percent volume moisture above permanent wilting percent, and day of growth beginning on May 1, 1954 and 1955. Solid curves indicate relationships with at least one partial regression coefficient significantly different from zero at the 5 percent level. The letter "m" indicates the mean of the independent variable and "s" indicates one standard deviation from the mean of that variable.*

tition on the soil moisture relationships may be observed in the curves for trees 1 and 2. The latter was in an area of higher competition, with soil drainage and leaf area comparable to that of tree 1. During both years, tree 2 exhibits greater reduction in growth rate associated with low soil moisture values.

The same comparison may be made between trees 5 and 6. Both were in similar sites with similar leaf areas, but the greater reduction of growth for tree 5 when soil moisture was low is associated with greater competition. This growth reduction in tree 5 occurred abruptly in 1955 when moist conditions were followed by the hot, dry weather of late July. The same phenomenon was earlier reported for another shallow-root beech growing on a poorly drained site of the same forest (Fritts 1956a).

The curves for growth against maximum air temperatures appear to have more similar shapes and more highly significant coefficients for the year 1955 than for 1954. Although one might at first conclude that temperature was more limiting in 1955, further experience with multiple regression of daily growth suggests that the divergent curve shapes during 1954 result from fitting an inappropriate curve. When temperatures generally range between 50-70°F, the growth-temperature curve bends upward concavely (Fig. 4), but for higher temperatures, the curve bends convexly. During 1954 there were a large number of cool days during May followed by very warm days during June and July. Since only a binomial curve (with one inflection) was fitted to the data, the curves fit neither the cool weather nor warm weather relationship closely. But during 1955 there were fewer cool days during May to counter the convex curve occurring at higher temperatures. Thus more trees exhibited significant coefficients and the curves in general were more similar in shape. If the cube of the daily maximum temperature had also been employed, a curve allowing for two inflections could have been obtained, and it is probable that such a curve would have more accurately represented the true growth-temperature relationships for 1954.

The curves for growth against day of growth (Fig. 1) have very similar shapes, and all coefficients are significant (Table 1). Variations due to differences in time of growth cessation are apparent. Especially noteworthy is the relatively early cessation of growth in trees 1 and 2 during 1954. The same trees were influenced greatly by the low soil moisture of that year. In 1955, tree 5 exhibits the most marked early cessation of growth due to adverse moisture conditions, as discussed previously.

The curves for growth on daily precipitation are plotted in Figure 2. No individual curve had a significant partial regression coefficient and markedly divergent trends are apparent. In the early treatment of the data, when a straight line was fitted and when all trees were treated as a unit (Fritts 1958), this factor proved positive and significant.

The absence of a consistent trend and of significant regression coefficients probably results from the fact that variation due to the related factor of soil moisture had already been accounted for. However, it is also possible that there simply were not enough data on this source of variation because rainy days were so few.

Average wind velocity was included as a factor with the expectation that an increase in wind would increase transpiration and thus reduce tree growth. But when a straight line was fitted to the data a significant positive relationship was obtained (Fritts 1958). However, when curves were used (Fig. 2), all relationships in 1954 exhibit a slight inverse effect at low wind velocities and a strong positive effect at high velocities. During 1955 only a positive trend is apparent.

If wind is important in increasing transpiration, which would thus reduce growth, then it appears from the curves that this influence must have been more effective during 1954 and largely restricted to lower velocities. This is in agreement with the current concepts concerning transpiration.

Meyer and Anderson (1952) state "A gentle breeze is relatively much more effective in increasing the transpiration rate than winds of greater velocity." The absence of the inverse relationship for growth on wind during 1955, however, may simply have

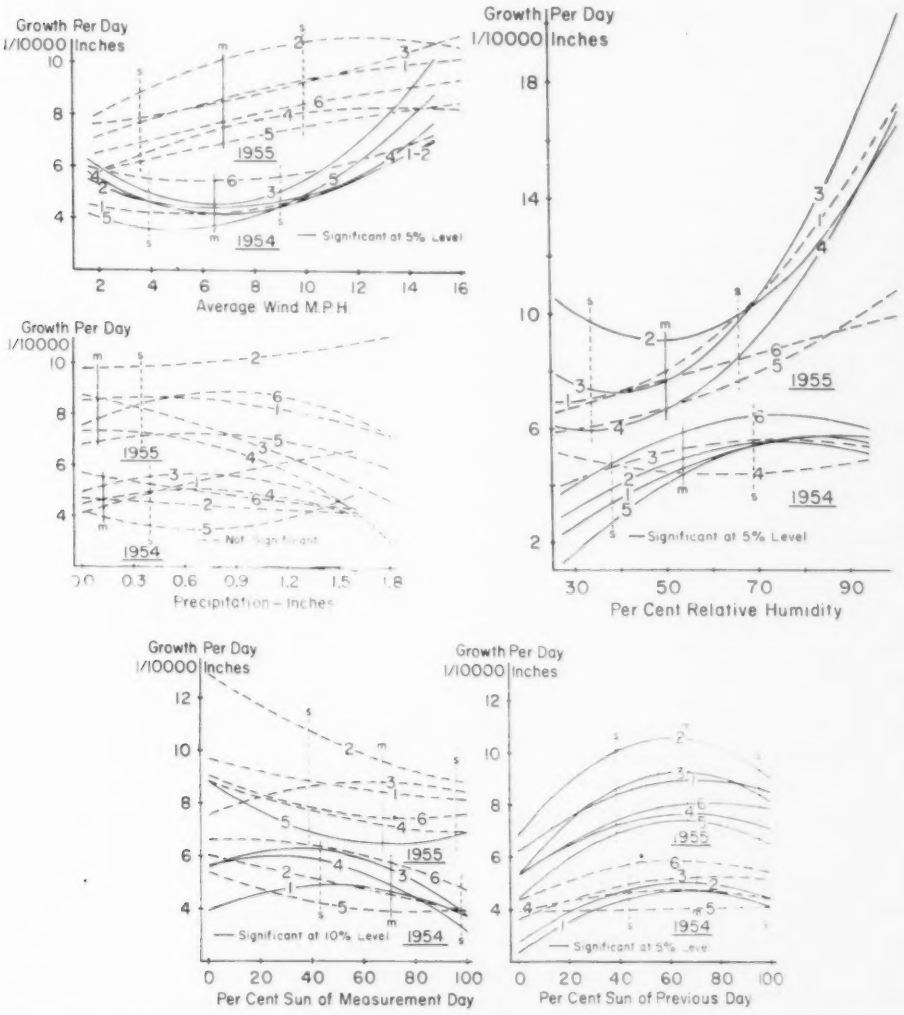

FIGURE 2. *The relation of daily radial growth of six beech trees on daily average wind velocity, daily precipitation, percent relative humidity at 1:00 pm EST, percent of sun of measurement day, and percent sun of previous day, 1954 and 1955. Solid lines indicate curves with at least one partial regression coefficient significantly different from zero at the 5 or 10 percent level, as indicated. No coefficient for growth on rainfall was significant at the 10 percent level. The letter "m" indicates the mean of the independent variable and "s" indicates one standard deviation from the mean of that variable.*

resulted from too few days in which wind was a direct limiting factor. The mean wind velocity was higher, and conditions of low soil moisture and high transpiration were not common until late in the season when growth was subsiding.

The explanation for the positive trend for higher wind velocities in 1954 and for all velocities in 1955 lacks a clear-cut physiological basis. A likely cause becomes apparent when the methodology and the micro-environmental characteristics of the study are considered. The relationship between the maximum temperatures in the forest stand and the open field where the temperatures were recorded may change with increasing wind velocity (Geiger 1957, p. 116). The differences between the temperatures measured in the open and those surrounding the growing trunks very likely become less with the higher wind. Since temperature is related directly to growth, the effect of high wind when included in the multiple regression analysis is to increase the tree temperature in respect to the measured temperature, and a positive curve results. It is hoped that in future studies the needed equipment will be available for an adequate sampling of the forest temperatures, thus enabling a better evaluation of the wind factor.

The curves for growth on percent relative humidity at 1:00 pm are for the most part consistent within either year, but in 1954 all except tree 4 bend convexly, and in 1955 all but tree 6 bend concavely. A similarity is apparent within one standard deviation of the mean relative humidity. Within this range, the slopes are positive in both years (except for tree 2 in 1955) and the amount of slope is proportional to the average growth for the season. If a straight line only had been fitted to the data, it is likely that both yearly regimes would have appeared about the same, thus leaving little doubt of a positive growth-humidity relationship.

The divergent growth-humidity trends may be partially explained as resulting from inadequate environmental measurement. The data represent single daily readings, rather than averages for the day. In addition, relative humidity units, although commonly used, are considered unsatisfactory by some workers for physiological studies (Meyer and Anderson 1952). Recent regression analyses have indicated that average vapor pressure deficit, as it influences transpiration, has a consistently negative relation to growth. This value, had it been available for the beech study, would probably have produced more consistent results.

The solid curves for growth on percent possible sun of measurement day (Fig. 2) represent relationships with coefficients significant at the 10 percent level; no partial regression coefficient was significant at the 5 percent or 1 percent level. Though this is a low level of significance, it appears that the relationship between growth and sunshine is generally negative. This would be expected, for increased sunshine would cause further stomatal opening and higher leaf temperatures, resulting in more rapid transpiration, a decrease in cell turgor, and finally, in less radial growth for that day.

The relation between growth rate and percent possible sun of the previous day, however, is generally a positive one. These curves are more consistent from tree to tree and from year to year than are the curves for any other environmental factor (Figs. 1 and 2). Both the high significance and consistent curve shapes reflect the close relationship between light, resulting sugar production in the leaves, and the time necessary for transport of the sugar down the stem to the area of growth measurement. With an increase in percent sun from 0 to 60, it appears that increasing photosynthesis and sugar production cause an increase in growth the next day. When the sunlight increases in the range above 80 percent, there is a decline in growth rate on the following day. This decline may very likely be due to excessive transpiration, causing partial closure of stomates and therefore a temporary reduction in photosynthesis in the middle of the day (Meyer and Anderson 1952). The fact that the highest positive

correlation with growth occurs on the day following is in agreement with Zimmerman's observations (Zimmerman 1958) on white ash (*Fraxinus americana* L.). He reports that in this species, the sucrose peak passes the 1 m level in the trunk early in the morning on the following day. Since, in the present study, midnight marks the end of the daily periods, little influence due to sugar production would appear until the following day. The frequent significance of the partial regression coefficients for growth on sun two days previous, but lack of significance for growth on sun three days previous, suggests that a small portion of the sugar may reach the measured level two days later, but rarely as long as three days. For the 1954 season when percent sun was greater and photosynthesis was not as limiting, only trees 1 and 2, which had the greatest relative leaf area, exhibit curves with significant coefficients.

It is apparent from the preceding multiple regression analyses that there is a large amount of similarity among the growth-environmental relationships of the six beech trees. A number of the existing differences among the various curves appear to be due to contrasting soil moisture regimes, different yearly climatic regimes, variations in crown size, and/or differences in competition from neighboring trees. By analyzing with separate multiple regression analyses on individual trees these differences can be assessed and in turn related to the ecological requirements of the species (Fritts 1959, and Fritts and Holowaychuk 1959).

Study 2: variations in growth among individuals of three tree species—early season growth of 1958. In this study, daily growth was measured by dendrographs during the early growing season of 1958. The trees measured included the same sugar maple and white oaks used in the Illinois study (Fritts 1959) mentioned earlier; added to them were two red oaks (*Quercus rubra* L.) Stem diameters and site characteristics of the study trees are included in Table 4. It should be noted that white oak 2, red oak 2, and the sugar maple are located on similar sites, while white oak 1 and red oak 1 are on sites contrasting to those of the other three trees.

The study period began on April 11, the approximate date marking the beginning of continuous daily growth in the oaks, and ended May 5-10, about the time the leaves had enlarged to one-half their final size. Continuous growth did not start in the sugar maple until April 14 and the growth rate was not as rapid as that of the oaks. A second sugar maple was also measured, but growth initiation did not occur until May 4, when leaves were already one-half expanded; therefore it was not possible to include this tree in the study.

TABLE 4. Stem diameters and site characteristics for the five trees studied during the spring of 1958.

Tree	Dbh (inches)	Percent slope	Site	Elevation above stream (ft.)
White oak 1	22.2	25	Upper south-facing	35
Red oak 1	19.8	60	Upper north-facing	24
White oak 2	21.2	35	Lower south-facing	13
Red oak 2	19.1	40	Lower south-facing	15
Sugar maple	18.2	40	Lower south-facing	13

A separate analysis of the growth period before full leaf expansion is appropriate here for several reasons. In the first place, the temperatures at the forest floor are more variable and higher when the canopy is not yet closed (Geiger 1957 and Wolfe *et al.* 1949). During this early period, maximum and minimum temperatures on the north-facing side of the dendrograph shelters averaged as much as two to three degrees above those in the thermograph shelter, which was located in an opening on the upland near the ravine. Temperatures inside the dendrograph shelters were even greater, averaging as much as four degrees above the thermograph readings. After the canopy closed, air temperatures in the forest averaged as much as two to three degrees below those in the thermograph shelter. A consistent relationship between thermograph and tree temperatures is maintained by analyzing the two periods separately.

Another reason for a separate analysis is that during this time leaves are not yet sufficiently formed to make transpiration and photosynthesis important factors, while both are major factors during the remaining growing period. Yet a third reason is that the oaks exhibit a peak in growth rate as buds are opening, and then a second peak in late May or June after the leaves are fully expanded. If both periods are included in a single analysis, a fourth and fifth power of the day number would have to be employed to fit a growth-time curve with two peaks.

Since the number of observations and number of variables were small, a graphical multiple regression analysis was used (Ezekiel 1941). The independent variables analyzed were average air temperature of the day of growth, average air temperature of the previous day, the difference between maximum and average air temperature, electrical resistance at a four-inch soil depth as measured by a Colman soil moisture meter, and day of measurement (beginning and ending at 7 am Central Standard time).

The adjusted indices of multiple correlation and their standard errors of estimate are presented in Table 5. It may be noted from the index of multiple determination that a large variance was accounted for in the analyses of the oaks, while much less was accounted for in the analysis of the sugar maple, probably due to the low growth rate of the latter tree.

TABLE 5. Coefficients and standard errors for graphical multiple regression analyses of radial growth in five trees during the spring of 1958.

Tree	Adjusted index of multiple determination	Adjusted index of multiple correlation	Adjusted standard error of estimate
Red oak 1	.774	.880	3.10
Red oak 2	.737	.858	3.06
White oak 1	.813	.902	3.77
White oak 2	.728	.853	5.19
Sugar maple	.466	.682	1.83

The growth - environmental relationships for white oak 2 and red oak 2 and the sugar maple, all located on the lower south-facing slope, are presented in Figure 3. The scattered points represent the final residuals for the respective curves. The curves for growth on average temperature of both the measurement day and the previous day are similar in shape. The major differences are that the red oak appears to increase in growth rate at slightly lower temperatures than the other two trees, and the white oak appears to be somewhat more affected by high temperature on the day previous to growth than are the other two species.

In order to compare the curves for the trees on contrasting sites and more precisely to evaluate the relationships, a consideration of the temperaturese at the point of measured cambial activity was necessary. Maximum and minimum temperatures in the dendrograph shelters were the best measurements available for this study. Daily readings were made for 24 days during the early spring growing period and the daily median temperatures were ascertained. A

simple linear regression and correlation was run between median temperatures for the thermograph shelter and those for each dendrograph shelter. The correlation coefficients ranged from .98 to .99. By means of the regressions, it was then possible to adjust the growth-temperature curves made with the thermograph readings to curves for growth on average temperature of each dendrograph shelter. This adjustment essentially corrected for temperature differences due to slope, exposure, and warming

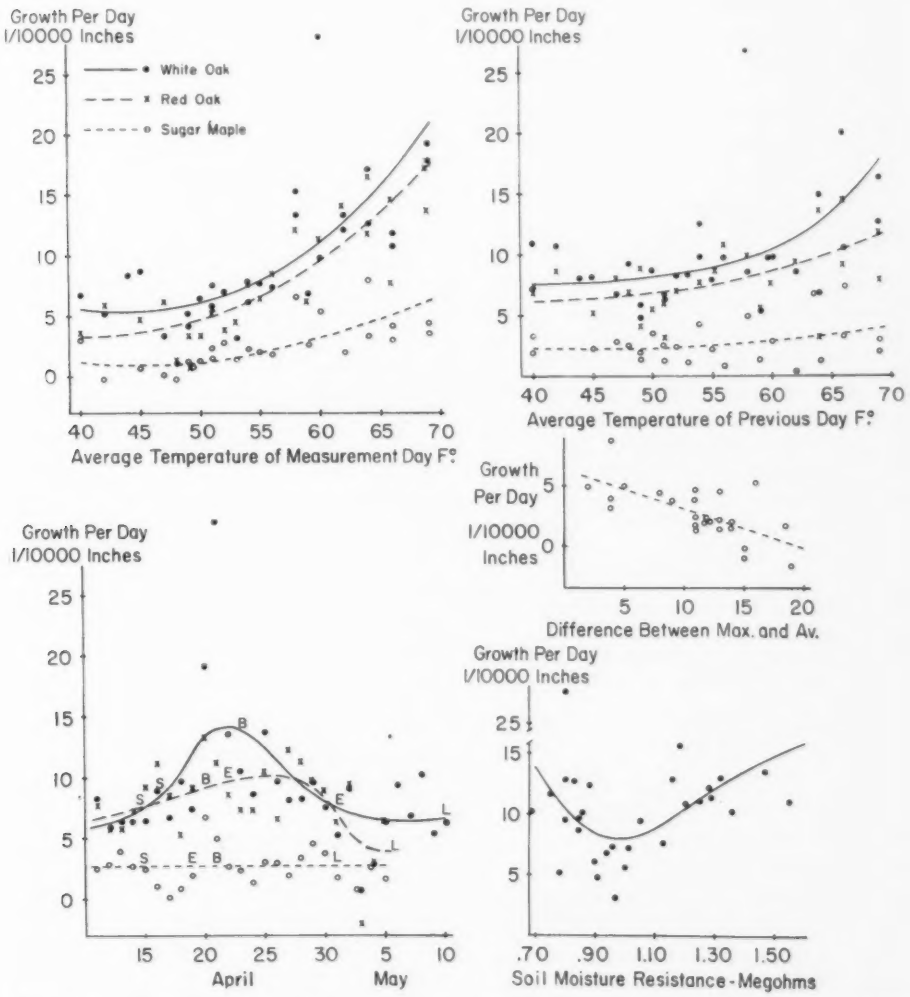

FIGURE 3. *The relation of daily growth on several environmental factors for white oak 2, red oak 2, and a sugar maple during early growing season, 1958. The curves were computed by graphical multiple regression techniques. Phenological events: S—buds definitely starting to swell, B—buds opening, E—leaves beginning to expand, and L—leaves expanded to ½ full size.*

of the shelter, and made it possible to plot together and compare growth-temperature curves for the trees (Fig. 4).

One can note from Figure 4 that both red oaks exhibit increased growth rate with an increase in average shelter temperatures between 45-50°F, while both white oaks show little increase in rate until average shelter temperatures rise above 50°F. The adjusted curves for growth on temperature of the previous day for the red oaks and sugar maple are not included, as the relationships appeared too slight to produce meaningful curves.

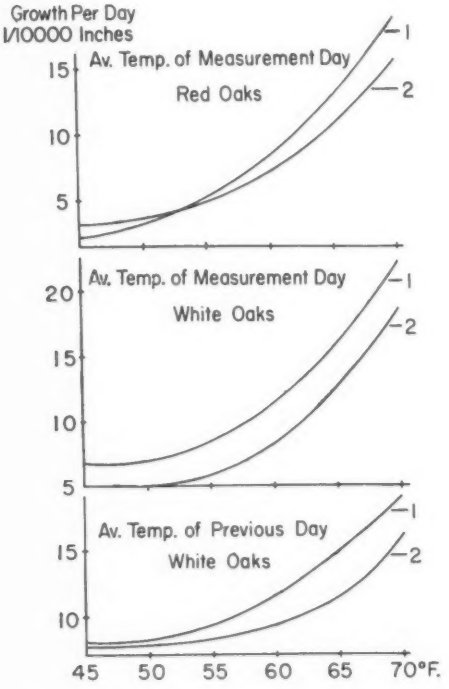

FIGURE 4. *The relation of daily growth in the four oaks to average temperature inside dendrograph shelters. Curves were computed by graphical multiple regression analysis, using average air temperature recorded by a thermograph. Each curve was then adjusted to respective dendrograph shelter temperatures by means of regressions between thermograph and shelter temperatures.*

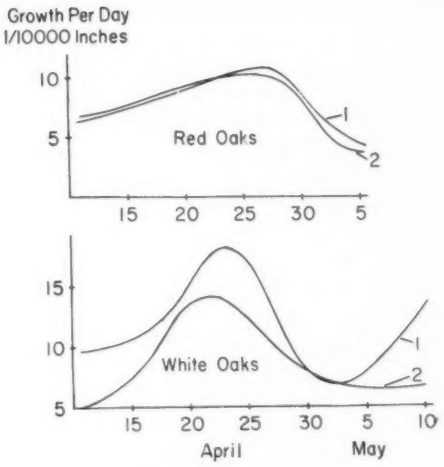

FIGURE 5. *The relation of daily growth in the four oaks to day of growth. Variations resulting from daily environmental changes have been removed by graphical multiple regression analysis.*

In the earlier study (Fritts 1959), the sugar maple appeared to reach optimum growth on days with maximum temperature near 68°F, while the white oaks had optima at maximum temperatures around 90°F. In order to allow for inhibiting effects of high maximum temperatures, the differences between the maximum and average temperature were included in the present analysis. The sugar maple was the only tree to show any trend here and, as would be expected from the earlier findings, it was an inverse relationship (Fig. 3).

The curves of growth on day of measurement represent the growth trend with the passing of time. In Figure 3 several of the phenological changes during this period are indicated with the growth-time curve. In white oak 2, the growth rate began to increase rapidly as the buds started to swell, reached an optimum at the time the buds began to open, and then dropped as the leaves unfolded and expanded to one-half their full size. In red oak 2, the optimum occurred slightly later when the leaves were already about one-fourth expanded.

In Figure 5 the growth-time curves for red oak 1 and white oak 1 are plotted with the curves for the other two oaks. The striking similarity between the individuals of the same species and dissimilarity between those of different species are obvious. The phenological development of red oak 1 and white oak 1 was similar to that of the oaks represented in Figure 3.

Growth ring measurements were made on the oaks at the end of the growing season and compared with dendrographic data. The accumulated daily radial increase occurring in the white oaks during the leafless period of April 11-May 10 was found to be comparable to the thickness of the spring wood formed during 1958. The daily radial growth of the red oaks during the leafless period of April 11-May 5 was comparable to only 2/3 of the total thickness of the spring wood. In these red oaks the accumulated daily growth reached the thickness of spring wood on approximately May 21. Sugar maple and beech, which are diffuse porous woods, exhibit no pronounced early maximum in growth rate. These data suggest that the early optimum in growth rate of oak, as well as an early initiation of cambial activity as described by Priestley (1935) and Wareing (1950), may be associated with the formation of porous spring wood. The growth of the white oaks only exhibits a relationship with soil resistance readings (Fig. 3). In white oak 2 the growth rate appears to be somewhat less when the moisture is near field capacity (0.95 megohm) than when it is either above or below this value. However, white oak 1 does not exhibit more rapid growth when soil moisture is below field capacity. Its curve approximates a straight line dropping with a rise in resistance, with the most rapid growth occurring when soil moisture is high (and resistance is low). The most significant point concerning these relationships is that both white oaks exhibit a change in growth rate associated with a change in soil moisture, while neither the red oaks nor the sugar maple show such a relationship during this early spring period.

This second study demonstrates that quantitative information on growth-environmental relationships may be obtained by multiple regression analyses of individual trees. A number of differences between species are apparent, even though the individuals measured were on similar sites. Considerable similarity within a species is apparent even when individuals are on contrasting sites. Although this study would be enhanced by additional measurements on other trees of the same species, it would appear that certain significant conclusions can be drawn from such analyses if care is taken to choose trees with comparable structure and competition, and to evaluate differences in micro-environment.

Conclusions

In the two studies presented, the approach is intensive rather than extensive. Instead of using large numbers to counteract the effects of individual variations, an effort is made to evaluate these variations. The results would probably have been more conclusive if more appropriate measurements had been obtained on some of the variables and if more flexibility had been allowed in certain curves. However, a number of fundamental relationships are apparent.

Temperature appears to be the most influential environmental control of growth. The curves of growth on temperature bend concavely upward with an increase in temperature in the lower ranges, but with higher temperatures an inflection occurs and the curves bend convexly to an optimum beyond which the growth rate declines. This optimum varies among species, but close similarities are noted within the species. The temperature of the day preceding growth may exert a similar but less pronounced effect on some species.

Soil moisture is also frequently associated with variations in radial growth. The studies bear out that it is especially limiting when it is present in excess amounts, causing poor aeration, or when it is dropping rapidly during prolonged rainless periods. In beech the growth rate appears to reach

its optimum when soil moisture values are in the intermediate range, but the statistical location of the optimum varies with the relative frequency of inhibiting values in the high and low ranges. Long-term factors of soil drainage, root distribution, degree of competition, crown size, and heredity all may influence the growth-soil moisture curves.

Sunshine appears generally to be inversely related to growth occurring before midnight, but is significantly and directly related to variations in growth on the two following days. The inverse effect of sunshine on growth of measurement day is probably due to high moisture stress within the tree, caused by rapid water loss in the crown and reduced hydration of growing tissues. The direct effect of sunshine on growth of the following two days is apparently due to transport of photosynthate to the measured region of the stem. But when percent possible sunshine exceeds 80, there is a slight reduction in growth rate the following day. Probably excessive transpiration and stomatal closure during midday result in a reduced rate of photosynthesis, with less photosynthate reaching the measured region on the following day. Sunshine appears more limiting and the coefficients more significant when the average sunshine for the season is low or the leaf area of the tree is large.

Wind at low velocities appears at certain times directly to influence transpiration and inversely to affect radial growth. An apparent positive effect of wind at higher velocities is thought to be associated with temperature differences in the study area, rather than being a direct causal factor of growth.

The relation of growth with relative humidity at 1:00 pm, although positive for both seasons studied, exhibits large variation between the two years. Rainfall, when isolated from the effect of soil moisture, bears no consistent relationship to daily growth.

The seasonal trend of growth rate for both beech and sugar maple has a single optimum occurring in June. Although red and white oak may exhibit a similar June optimum, another earlier and more pronounced growth peak is apparent while the buds are breaking dormancy in April and May. The magnitude of growth during this spring period suggests a relationship between the occurrence of the early optimum and production of porous spring wood in the oaks.

Before this type of analysis on daily radial growth can have wide application, basic problems arising from environmental measurement, experimental design, and differences in climatic regimes should be more fully explored. As progress is made in the mathematical representation of causal factors which influence the physiological processes, results should become more consistent. Even then, unassessed variation should be expected due to such things as genetic differences, physiological preconditioning, and error of measurement. Also, it should be recognized that an intensive study on a few trees affords only an indication of what might be expected for a whole forest or throughout the range of a particular species.

In using multiple regression, one must keep in mind that although quadratic, cubic, and higher order regressions are convenient for analysis of biological data and frequently give a reasonably good fit, other curves such as a cycloid or sine curve may present a more logical interpretation.

Also, one must remember that an environmental variable may be significantly correlated with several other factors, one or more of which may have a direct influence on growth. Such a correlation may cause the factor in question to appear more related to growth than it actually is, especially if the causal factors with which it is correlated are not included in the analysis. In addition, interaction between factors may occur in such a way that the products of pairs of factors may be necessary to evaluate the joint functional relationships involved. There should also be consideration of the fact that factors limiting growth may change throughout the growing season

and in different climatic regimes. In the past, sorting out such complications was a hopeless job, but with recent developments in computor programs and designs, the task is not an impossible one.

In evaluating results, one must keep in mind that multiple regression techniques merely measure correlated variations and do not necessarily establish cause and effect relationships. A decision as to whether a relationship is truly a causal one must be made by the investigator, using his knowledge of the physiological processes involved. Above all, multiple regression analysis must never be considered as an end in itself, but rather should be thought of as a tool useful for clarification of the relationships involved in the growth-environmental complex.

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Saponin—A Seed Germination Inhibitor

BY
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GEORGE R. VAN ATTA

ESTABLISHMENT of browse species, either native or introduced, by artificial seeding on severe range sites is difficult at best. One of the main hindrances is slow, uncertain seed germination. Many workers have attributed poor germination to seed dormancy; of more than 400 tree and shrub species studied by the U. S. Forest Service (1948), nearly two-thirds showed some form of dormancy.

Imperviousness of seedcoats to water has long been recognized as a deterrent to germination and is easily corrected by scarification. In fourwing saltbush (*Atriplex canescens* (Pursh) Nutt), for example, heavy scarification which removes the winged appendages and abrades the seedcoat greatly hastens and increases germination. But water absorption isn't the whole story. Beadle (1952) believed germination of the seeds is inhibited by chloride they contain. Later, Koller (1957) presented evidence that germination is inhibited not by chloride but by an unidentified water-soluble substance in the fruit bracts. Miller (1919) reported the presence of a saponin, one of a large group of complex glycosides, in *Atriplex canescens*. Sigmund (1914) had produced evidence of an inhibitory effect by certain saponins on germination and seedling development.

More recently Varshney and Farooq (1953) found that saponin from an Indian legume (*Albizzia lebbek* Benth) in very dilute solutions stimulated germination and seedling development in wheat, barley, and chick-peas. They also reported an inhibitory effect by stronger solutions. It has been demonstrated that poor germination and growth of cotton planted to follow alfalfa in rotation was due to saponins leached into the soil from alfalfa roots (Mishustin and Naumova, 1955).

Pearson (1957) was able to break seed dormancy in antelope bitterbrush (*Purshia tridentata* (Pursh) DC) with a weak solution of thiourea, but he did not determine the action of the thiourea. Similar work with fourwing saltbrush by the authors led to the discovery of saponin in this species. Recovery of this substance from fourwing saltbush millings and subsequent seed germination tests have provided the material for this report.

For the past several years the junior author has been investigating the nature and properties of the saponins of dehydrated forage legumes. These saponins are known to inhibit growth in chicks fed high levels of these products. Since back-

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The authors acknowledge the translation of Mishustin and Naumova's article from Russian into English by Bertha P. Debeau, Western Utilization Research and Development Division, Agricultural Research Service, Albany, California.

ground and methods of saponin research could be applied directly to the present problem, the cooperative work described here was a natural development.

Recovery and Characterization of Saltbush Saponin

Chaff produced by scarifying fourwing saltbush seeds was defatted with ether and extracted with 80 percent alcohol. The saponin was recovered from the alcoholic extract by precipitating with ether. The recovered saponin was about 10 percent of the weight of the original chaff.

A sample of the saponin was hydrolyzed with acid to obtain the sapogenin which is the nucleus of the saponin molecule. Its X-ray diffraction pattern and infra-red spectrum proved that the sapogenin was oleanolic acid. This identification showed that the saponin belongs to the triterpenoid class. The carbohydrate portion of the saponin molecule was not examined.

Seed Germination

Fourwing saltbush and antelope bitterbrush seed from lots that had germinated well in the field and laboratory were tested in various saponin solutions. The fourwing saltbush seed had been scarified and passed over a 1/12-inch screen (Nord and Whitacre, 1957). Separate lots of seeds were soaked 4 hours in 0.1, 1.0, and 5.0 percent solutions of saponin in distilled water. After air drying for 24 hours, the seeds were put on filter paper in covered petri dishes for germination.

Bitterbrush embryos were excised from presoaked seeds and placed directly in petri dishes. The seeds of each lot were kept moist with the same solution in which they had been presoaked. Each test included 8 replications of 50 seeds each.

In an additional test, bitterbrush seeds were pretreated with thiourea. These seeds were immersed for 3 minutes in a 5 percent thiourea solution, then air dried. Otherwise and except that only 2 replications of seed lots were used, this test was conducted under the same conditions applied to the other lots of seed.

Results

Seed germination was significantly depressed in both species treated with 1 and 5 percent saponin solutions. Inhibition increased with saponin concentration. Germination was slightly but not significantly higher with 0.1 percent saponin than with water alone:

	Germination in 15 days (percent)	
	Fourwing saltbush	*Antelope bitterbrush*
Treatment:		
Water (control)	49	50
0.1 percent saponin	50	57
1.0 percent saponin	33	35
5.0 percent saponin	23	17

Bitterbrush seeds pretreated with thiourea and moistened with 5 percent saponin solution showed only 20 percent germination. Moistening with more dilute solutions and water alone permitted 70 percent germination.

Seeds of the two species moistened with the stronger saponin solutions displayed different germination behaviors. In saltbush, germination practically stopped after the sixth day in 1.0 and 5.0 percent solutions (Fig. 1). Although total germination of bitterbrush was greatly lessened, bitterbrush seed moistened with similar solutions continued to germinate throughout the observation period (Fig. 2).

Tests showed that dry saltbush fruits can absorb about one and one-half times their own weight of water. Since the seedcoats are about 10 percent saponin by weight, it follows that when the fruits are moistened to their full capacity, the solution formed within the tissues contains about 6.5 percent saponin, provided that none is lost by leaching.

Mold appeared in 4 days and spread profusely in cultures containing saponin. In the controls, mold did not develop until the tenth day. Many of the seedlings developed in the saponin solutions were abnormal. About one-fourth of the fourwing saltbush seedlings had brown root tips that appeared injured. Bitterbrush seeds that germinated in the stronger solutions

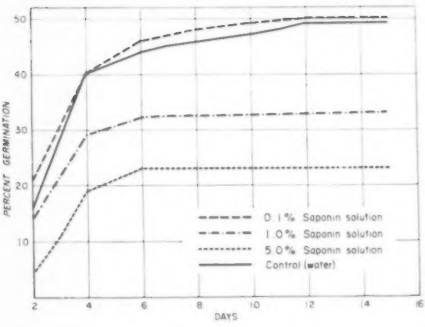

FIGURE 1. *Germination of fourwing saltbush seed as affected by saponin.*

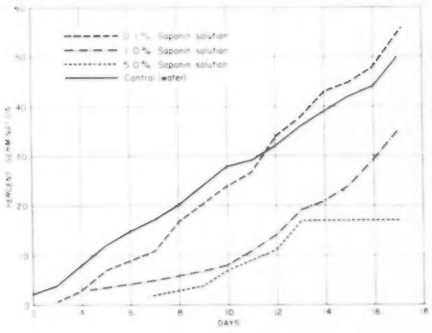

FIGURE 2. *Germination of bitterbrush seed as affected by saponin.*

showed weak elongation and appeared incapable of continued survival. In water alone, both species produced well-developed roots with small but visible growing points.

Discussion and Conclusions

The identification of saponin in fourwing saltbush confirms earlier findings by Miller (1919). Its occurrence in the seedcoat and bracts was well established, and its presence was indicated in other plant tissues. Qualitative tests also indicate that similar occurrence of a saponin in bitterbrush is probable. The saltbush millings yielded about 10 percent crude saponin by weight. This was positively identified as a glycoside of oleanolic acid.

Our tests with fourwing saltbush and bitterbrush seeds generally parallel the work of Varshney and Farooq (1953) and Mishustin and Naumova (1955), which demonstrated that at moderate concentrations saponins significantly reduced seed germination, whereas at lower concentrations, saponin stimulated germination. These earlier observations were based exclusively upon tests in which saponins from one or another species were applied to seeds of different species. In the tests reported here, saponin was applied to seed of the same species from which it was obtained as well as to the seed of another species.

The results of these experiments throw light on some phenomena of seed dormancy in fourwing saltbush and suggest why seed processing increases germination. Seed dormancy in fourwing saltbush is due predominantly to the saponin contained in the winged bracts and seedcoat. This was clearly demonstrated by the inhibitory effect that 1 and 5 percent saltbush saponin solutions had upon germination in two browse species. Both concentrations were lower than those that would exist within the seedcoat and bracts if only enough water were added to moisten the intact untreated saltbush seed. When the seeds are soaked in water to increase germination, much of the saponin dissolves in the water and is thus removed. In either species, germination is benefited by removal of saponin. This conclusion agrees with the outcome of an earlier test in which heavily scarified seeds gave the best germination (Nord and Whitacre, 1957). In addition to removing saponin mechanically, scarification abrades the seedcoat and makes it more porous, which in turn favors removal of saponin by leaching during presoaking and after planting.

Since germination of bitterbrush seed was significantly inhibited by saltbush saponin, a saponin in the inner seedcoat of bitterbrush may be one factor responsible for poor germination in that species. This possibility has not yet been investigated.

These experiments concerned only the saponin in the seed and its relation to ger-

mination. No tests were made under field conditions. This subject needs further investigation to ascertain the full significance of saponins to germination and seedling growth of fourwing saltbush and other species. Such knowledge is basic to the development of more effective methods of overcoming seed dormancy in browse plant species.

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Influence of the Pitch-Eating Weevil On Pine Regeneration in East Texas

BY
ROBERT C. THATCHER

WEEVILS THAT ATTACK young pine seedlings are becoming increasingly important in the regeneration of pine forests in the South. This is particularly true in recently cut areas where rapid encroachment of hardwoods places a premium on establishment of seedlings, natural or planted, within the first year after the old stand is removed.

Two weevils—the pales weevil, *Hylobius pales* (Hbst.), and the pitch-eating weevil, *Pachylobius picivorus* Germ.—are attracted to and breed beneath the bark of dying pine stumps or roots. As larvae, they are of little economic importance, but the adults feed on the bark or foliage of pine seedlings and kill them.

While the pales weevil has received considerable attention in the South (Speers, 1958; Beal and McClintick, 1943; Sentell, 1949), little is known about the pitch-eating weevil. This paper reports on research in east Texas to learn the life history of the insect and discover how its depredations are related to the season in which pine stands are cut.

When the studies were begun in 1955, it was assumed that the pales weevil was responsible for most of the damage that had been observed in east Texas. It was found, however, that the pitch-eating weevil comprised about 85 percent of the local weevil population and caused an even higher percentage of the injury to pine seedlings.

Life History and Habits

Portions of the root systems of pines cut during summer, fall, winter, and spring in 1955-57 were excavated at intervals during 1956 and 1957 to study the life history of the weevil and the relation of adult emergence to feeding damage. Populations in roots were found to be exclusively the pitch-eating weevil. No evidence of brood development in stumps or sections of logs was observed.

To oviposit, adults burrow directly down to green roots, leaving a small pile of large soil particles around an open entrance hole on the soil surface. Burrowing may occur 25 feet or more from the stump. Eggs are deposited in the cambial region of roots as little as 0.2 inch in diameter. Depending on the season, they may hatch within a week.

The newly hatched larvae feed beneath the bark. The larval mines are tightly filled with fine, red boring particles. The surface of the root sapwood may be etched, depending upon the number and stage of development of the larvae and the size of the root. Larvae were found in roots to depths of at least 36 inches.

As their development nears completion, the larvae etch the root sapwood deeply, causing white boring particles to become mixed with the red. Finally, they excavate cells and construct chip cocoons in which transformation to the adult stage occurs

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(Fig. 1). When populations are large, pupal cells may be formed within the wood. Emerging adults chew a round exit hole through the root bark and apparently move directly to the soil surface.

New adults emerge when stump root systems are 6 to 11 months old, depending upon the season in which the trees were cut (Table 1). They fly to fresh cutting areas where they feed and repeat the cycle.

Like the pales weevil, the adult pitch-eating weevil feeds mainly at night and on cloudy days, and concentrates on seedlings near fresh stumps. In the South both do their major damage early in the growing season, but some injury can be expected in the fall.

The nature of injury varies seasonally and with the size and vigor of the host. Damage is severe early in the spring following planting: frequently all bark, buds, and foliage are removed to the groundline. Portions of the root bark may be removed to depths of 8 inches. Newly established natural seedlings, if attacked at all, are usually severed. As the season advances, damage becomes less severe, more often involving patch-feeding (Fig 2) and puncture wounds (Fig. 3). Very little feeding takes place in July and August. During the fall, limited feeding is resumed but causes little mortality of seedlings.

TABLE 1. Relation of season of cut to emergence of adult weevils from root systems of pine stumps.

Time of cut	Time of weevil emergence	Time between cutting and emergence *Months*
Aug. 1955	June–July 1956	10–11
Oct. 1955	Aug.–Sept. 1956	10–11
Jan. 1956	Brood failed to mature	——
Apr. 1956	Oct.–Nov. 1956	6– 7
July 1956	June 1957	11
Oct. 1956	July–Sept. 1957	9–11
Jan. 1957	Oct.–Nov. 1957	9–10
Apr. 1957	Oct.–Nov. 1957	6– 7

Season-of-Cut Study

To study weevil activities in relation to time of cutting, shortleaf-loblolly pine stands were harvested from the Stephen F. Austin Experimental Forest near Nacogdoches, Texas at three-month intervals between August 1955 and April 1957.

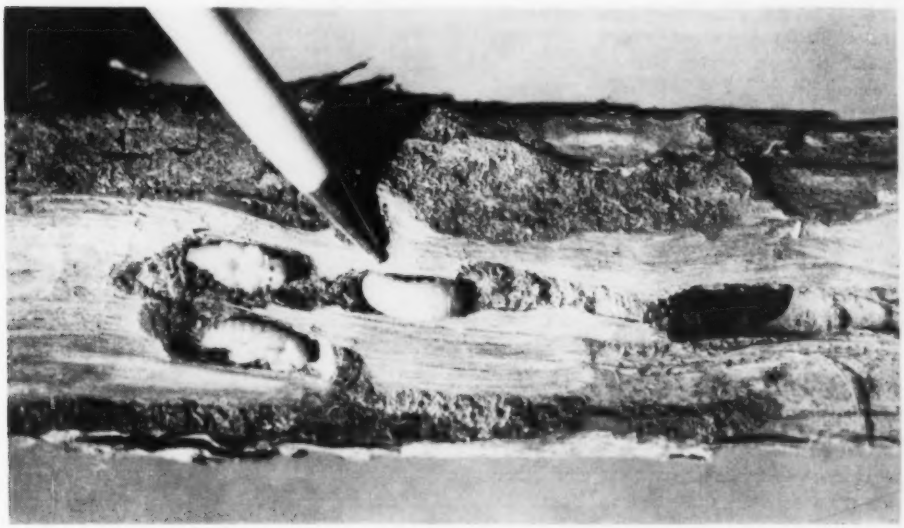

FIGURE 1. *Adult, larva, and pupae of pitch-eating weevil in a pine root.*

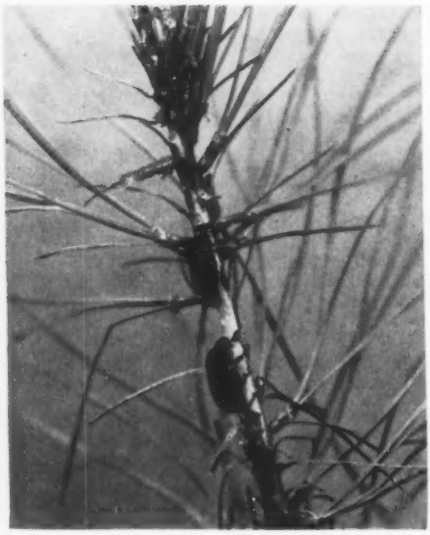

FIGURE 2. *Weevils have eaten large patches of the bark of this loblolly pine seedling. This type of feeding, which occurs during late spring and early summer, often kills seedlings.*

Design

Twenty-four half-acre plots were located in areas with a dense hardwood understory and a medium to heavy pine overstory. All hardwoods were either cut or girdled and treated with 2,4,5-T before pine seedlings were planted.

The plots were stratified into three groups by site and stand conditions. All pine was cut from one randomly selected plot from each group on each of the following dates:

Summer harvests—August 1955, July 1956
Fall harvests—October 1955, October 1956
Winter harvests—January 1956, January 1957
Spring harvests—April 1956, April 1957

Within the central portion of each plot, two blocks 44 by 104 feet were established, one randomly assigned to seed spots, the other to planted seedlings. Blocks were separated by 12-foot isolation strips. Eight rows of loblolly pine, two rows of slash pine, and two rows of shortleaf pine seedlings were planted on one block and sown on the other. There were 25 seedlings or seed spots in each row.

Seed spots were established on all plots in January 1956. Failed spots were resown in January 1957. (January is about the middle of the planting season in east Texas.)

On plots cut during 1955 and the first half of 1956, seedlings were planted in January 1956. All plots were planted in January 1957, the new rows on the previously planted plots being set halfway between the existing rows. Similarly, the plots which were cut after midyear in 1956 were replanted in January 1958.

Results

Cumulative incidence of weevil attack and mortality are tabulated for planted seedlings in Table 2 and for seedlings grown from seed in Tables 3 and 4. Data for planted

FIGURE 3. *Puncture-wound feeding may weaken seedlings but seldom is fatal.*

loblolly pine are most reliable, since they are based on four times as many seedlings as those for the other two species.

Planted seedlings.—Plots planted in January 1957 afford the most complete appraisal of the relation of time of cutting to weevil damage (Table 2).

On all cuttings more than 9 months old at the time of planting, weevils attacked less than 1 percent of the planted seedlings and killed an even smaller proportion. Such damage is negligible from the standpoint of pine regeneration.

TABLE 2. Weevil attack during first growing season after pine planting.[1]

Season of cut and species	January 1956 plantings		January 1957 plantings		January 1958 plantings	
	Seedlings attacked by weevils	Seedlings killed by weevils	Seedlings attacked by weevils	Seedlings killed by weevils	Seedlings attacked by weevils	Seedlings killed by weevils
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
August 1955						
Loblolly	35.7	17.3	0.7	0.0		
Shortleaf	13.3	5.3	.0	—		
Slash	26.0	19.3	.7	.7		
October 1955						
Loblolly	65.3	43.2	.8	.3		
Shortleaf	56.0	34.7	.0	—		
Slash	57.3	45.3	.0	—		
January 1956						
Loblolly	67.5	34.2	.5	.2		
Shortleaf	49.3	24.3	.0	—		
Slash	54.0	38.0	.0	—		
April 1956						
Loblolly	68.3	23.3[2]	9.3	3.3		
Shortleaf	50.7	16.0	2.0	.7		
Slash	57.3	38.7	1.3	.0		
July 1956						
Loblolly			32.0	8.2	0.3	0.0
Shortleaf			14.0	4.7		
Slash			26.7	12.0		
October 1956						
Loblolly			76.7	60.2	.4	.0
Shortleaf			52.0	32.0		
Slash			55.3	42.7		
January 1957						
Loblolly			74.8	40.0	.8	.0
Shortleaf			54.0	41.3		
Slash			46.7	22.0		
April 1957						
Loblolly			61.5	30.0[2]	1.7	.0
Shortleaf			40.7	12.7		
Slash			48.0	20.0		

[1]During the January 1956 and January 1957 planting periods, a total of 600 loblolly, 150 shortleaf, and 150 slash pine seedlings were planted on each season-of-cut plot series (3 plots). During the January 1958 planting period, 900 loblolly and no shortleaf or slash pine seedlings were established on each replanted second-year season-of-cut plot series (3 plots).

[2]These plots were cut three months after planting. When replanted the following winter, they suffered very little weevil damage.

On plots cut in April 1956, 9 months prior to planting, 9 percent of the loblolly seedlings were attacked, and about 3 percent were killed. Injury was somewhat lower on the other two species.

On plots where cutting had occurred more recently than the previous April, and on those cut 3 months after planting, both incidence of attack and seedling mortality were heavy. Most serious damage occurred on October cuttings; here 77 percent of the loblolly seedlings were attacked and 60 percent died. January cuttings resulted in about the same degree of attack but in only 40 percent motrality. Damage on plots cut in July was intermediate between that on April and October cuts.

Results from the January 1957 plantings were substantiated on plots with seedlings planted in January 1956 and January 1958.

Differences between seasons of cutting were statistically significant when expressed as percentages of seedlings attacked or killed. Differences between years were not statistically significant.

Second-year seedlings grown in place. During 1957, all plots had pines grown from seed sown in January 1956. These seedlings were comparable in age, though somewhat inferior in size, to those planted in January 1957. Damage on plots of the second-year cutting series was recorded to determine the level of weevil activity on seedlings that had not been subjected to the shock of transplanting (Table 3).

Within seasons, the pattern of attack and mortality for two-year-old sown pines corresponded with that for planted seedlings of the same age. Differences associated with season of cut were less extreme for in-place seedlings than for transplanted ones, and were not statistically significant. For all seasons of cut, incidence of attack was lower on sown than on planted seedlings, but the proportionately higher mortality indicates that the attacks were more injurious, probably because the seedlings were smaller.

First-year seedlings grown in place. Weevil damage to first-year seedlings grown from seed is summarized in Table 4. Incidence of attack and mortality among these small seedlings was low on all cutting areas.

Seasonal trends and nature of weevil damage. Incidence of weevil attack and seedling mortality followed closely parallel trends on comparable cutting areas each year. Figures 4 and 5 show trends for loblolly in 1956 and 1957 on plots cut within 9 months of the time of planting. On older cuttings there were too few attacks to establish reliable trends.

In both years attacks first occurred in February. Maximum feeding took place during April and May on plots cut in October and January. Since all this feeding occured before weevils could have developed and emerged on these plots, the damage obviously was by weevils attracted from areas cut during the early part of the previous year.

On plots cut the previous July or August, early attacks were less frequent, but a relatively slow, steady rate of attack was

TABLE 3. Attack and mortality during 1957 for seedlings second year in place (sown January 1956).

Season of cut and species	Seedlings	Seedlings attacked	Seedlings killed
	Number	*Percent*	*Percent*
July 1956			
Loblolly	203	13.8	10.3
Shortleaf	141	3.6	2.1
Slash	140	11.4	6.4
October 1956			
Loblolly	57	42.1	31.6
Shortleaf	39	33.3	33.3
Slash	9	44.4	44.4
January 1957			
Loblolly	165	43.6	37.0
Shortleaf	46	23.9	23.9
Slash	18	33.3	27.8
April 1957			
Loblolly	253	43.5	39.5
Shortleaf	46	26.1	26.1
Slash	37	51.4	51.4

TABLE 4. Attack and mortality for seedlings first year in place.

Time of cut and species	Seedlings	Seedlings attacked	Seedlings killed
	Number	*Percent*	*Percent*
JANUARY 1956 SOWINGS			
August 1955			
Loblolly	1,782	0.1	0.0
Shortleaf	818	.0	—
Slash	494	.0	—
October 1955			
Loblolly	1,481	1.2	.8
Shortleaf	1,028	.3	.3
Slash	422	.5	.5
January 1956			
Loblolly	1,532	.4	.2
Shortleaf	874	.8	.8
Slash	488	3.1	1.6
April 1956			
Loblolly	1,939	2.2	.6
Shortleaf	807	.1	.0
Slash	560	7.1	2.5
JANUARY 1957 SOWINGS			
July 1956			
Loblolly	3,066	.8	.6
Shortleaf	767	.1	.1
Slash	505	.0	—
October 1956			
Loblolly	3,513	5.1	3.0
Shortleaf	844	2.0	1.8
Slash	711	18.4	14.5
January 1957			
Loblolly	3,194	2.4	1.8
Shortleaf	831	1.1	.8
Slash	633	8.2	6.2
April 1957			
Loblolly	2,695	5.2	3.0
Shortleaf	859	7.7	6.3
Slash	537	19.0	16.2

maintained. On all plots, a slight rise in feeding incidence began in September and continued until November.

On plots not cut until the April following planting, feeding began late in April (Fig. 6), increased rapidly well into July, and then leveled off slightly.

Only in the spring did the trends of mortality approach those of incidence of attack — after the spring period of heavy

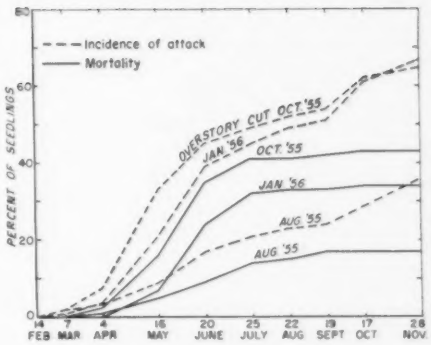

FIGURE 4. *Cumulative damage to loblolly pine seedlings planted January 1956.*

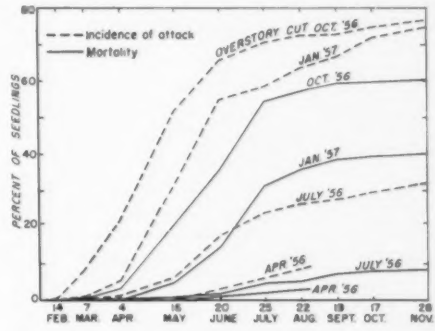

FIGURE 5. *Cumulative damage to loblolly pine seedlings planted January 1957.*

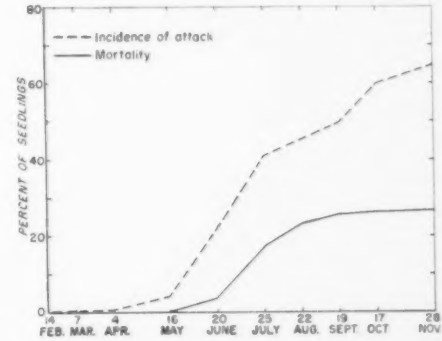

FIGURE 6. *Cumulative damage on plots from which overstory pines were cut in April, 3 months after loblolly pine seedlings had been planted. Data are averages for 1956 and 1957 plantings.*

feeding, mortality fell distinctly below attack percentage for each season of cut. In part, this reflects a lag between attack and mortality. It also indicates that many late-season attacks were not lethal, because the feeding scars were smaller and mostly on the new growth rather than on the main stem or base of the seedling. In addition, stumps and roots on plots cut the previous year were no longer sufficiently attractive to hold large numbers of newly emerged weevils in the area or to induce other weevils to immigrate.

Attacks on two-year-old seedlings grown in place followed approximately the same seasonal pattern as for planted seedlings of comparable age. In contrast, first-year seedlings suffered very little during the early spring and summer, when they were slender and only an inch or two high. Only in late summer, when some had grown to heights of 6 inches or more, did weevil feeding become appreciable.

Species comparisons. In both 1956 and 1957, the percentage of seedlings attacked was significantly higher for loblolly than for slash or shortleaf. Mortality rates were not consistent. Slash pine had a significantly higher rate (Chi-square) in 1956 than the other two species, but in 1957 the rate for loblolly was significantly higher than for slash and shortleaf. Two-year-old seedlings grown in place exhibited no significant species differences in mortality. Mortality among first-year seedlings grown in place was highest for slash pine, but the differences between species were not significant.

Within seasons, the pattern of attack was nearly the same for all pine species.

Discussion

Weevil damage in relation to season of cutting. In east Texas, weevils often kill 35 to 60 percent of planted pine seedlings where overstory pines have been cut within 3 months of the planting season. However, pine stumps deteriorate very rapidly in this region and attract weevils for only a short period. This study has shown that areas cut in July or earlier and planted the next winter will have very few weevils by the following spring. Unless additional cutting has provided new stumps, weevils that develop and emerge in such areas will migrate to more recent cuttings before doing much feeding.

Where reliance is being placed on natural regeneration, cuttings should be made to coincide with periods of heavy seedfall, so as to take advantage of minimum hazard of weevil damage to first-year seedlings. By the time the seedlings reach susceptible size, the area will have lost its attractiveness to weevils. Advanced reproduction (1 to 3 years of age) is likely to be as seriously damaged as planted stock, particularly where growth has been poor. If such seedlings are abundant and making good growth, it may be desirable to delay cutting until they reach more resistant sizes.

Direct control. If planting must be done within 6 months after pines are harvested, losses from weevils can be reduced by dipping the planting stock in chemicals (Speers, 1958; Thatcher, 1958). Water suspensions containing 1.0 percent of dieldrin or the gamma isomer of BHC, or 2.0 percent water emulsions of aldrin or heptachlor, have proved effective. The BHC suspension should only be used as a top dip, since the chemical is toxic to seedling roots. Seedlings may be completely immersed for brief periods in the other chemicals.

Summary and Conclusions

Studies in east Texas during 1955-58 showed that pine weevil populations were composed primarily of the pitch-eating weevil. The adults burrow down to stump roots, where they lay eggs. Broods develop in 6 to 11 months, depending on the season in which they become established. Adults may emerge at any time during the growing season.

On plots where overstory pines were cut within 3 months of the time pine seedlings were planted, weevil feeding resulted in heavy mortality of planted loblolly, shortleaf, and slash pine seedlings; natural

seedlings of comparable size were also attacked. Damage was much less on areas cut in July before planting in January, and negligible on areas cut in April or earlier. Incidence of attack did not significantly vary with pine species.

The most severe weevil attack and seedling mortality occurred between March and June. Following 2 months (July, August) of relative inactivity, weevils resumed feeding until late November, but caused negligible seedling mortality.

All spring feeding was by adults drawn into recently cut plots from other areas. Late fall feeding, however, was apparently by adults newly emerged from roots of stumps on plots cut the previous fall, winter, and spring.

Damage to seedlings during their first year from seed was negligible.

It is concluded that in east Texas:

Pine seedlings may safely be planted on areas cut earlier than the previous July. A longer wait may be necessary in the more northerly portions of the southern pine range.

Seedlings to be planted on areas from which pine has been cut within 6 months should be protected by chemical treatment.

Advance reproduction 1 or 2 years old may suffer heavy mortality. One or two years' delay in cutting may enable such seedlings to outgrow their vulnerability.

Regeneration cuts may be made during seed years with little fear of excessive losses from weevils.

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Statement of the ownership, management, etc., required by the Act of Congress of August 24, 1912 as amended by the Acts of March 3, 1933 and July 2, 1946 (74 Stat. 208) of FOREST SCIENCE, published quarterly at Baltimore, Md., for December, 1960.

DISTRICT OF COLUMBIA

Before me, a Notary Public, Washington, D. C., personally appeared L. Audrey Warren, who having been duly sworn according to law, deposes and says that she is the Business Manager of FOREST SCIENCE and that the following is, to the best of her knowledge and belief, a true statement of the ownership, management, etc., of the aforesaid publication for the date shown in the above caption required by the Act of March 3, 1933, embodied in section 537, Postal Laws and Regulations, to wit:

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Sworn to and subscribed before me this 16th day of September, 1960 (seal). Spencer T. Money, Notary Public, Washington, D. C. (My commission expires May 15, 1969.)

A Simple Device for Weight-sorting Seeds

Equipment note by John W. Duffield
Industrial Forestry Association, Nisqually, Washington

Because seed and seedling weight are often correlated in conifers,[1] the control of seed weight is an important feature of experimental technique in genetic and physiological studies of conifer seedlings.[2, 3] Size classification by screening is unsatisfactory, especially when the seeds are irregular in shape; air column separation is unreliable. Modern automatic balances facilitate rapid weighing of single seeds in the 5 to 50 milligram range, but the cost of such balances is high, their precision is greater than needed, and the manipulations of seed and balance controls are time-consuming.

The device illustrated in Fig. 1 is modified from a glass fiber balance described by Sax,[4] to permit rapid weight-sorting by the addition of magnetic damping and an unloading device which removes the objects weighed from the balance pan and deposits them in a container appropriate to their weight class.

Magnetic damping is achieved, as in conventional 2-pan balances, by placing an aluminum vane between the poles of a pair of horseshoe magnets. For the fiber balance, the vane is of household aluminum foil measuring 1 x 2.5 cm, cemented to the fiber about 3 cm back of the pan, which is also made of aluminum foil of a size appropriate to the seed to be weighed.

The fiber is made by drawing out 5 mm glass tubing. The unmodified tubing at the base of the fiber may be bent at a right angle to the axis of the fiber, and inserted in a clamp or block of wood bored to fit. This permits adjustment of the height of the balance pan under a given load. It is expedient to draw out several fibers of different sensitivities. Within practical limits, which should be explored for each fiber used, such a fiber shows a linear relation between load and deflection. The fiber illustrated is deflected 1.5 mm per mg over the range from 0 to 20 mg, which is convenient for seeds of *Pseudotsuga menziesii* (Mirb.) Franco. This linear relationship permits the use of a linear arrangement of pan-unloaders, which are the widely-separated teeth of a "comb." The inclination of the comb can be adjusted so that the difference in elevation between successive teeth varies from 0 (no sorting) to more than the thickness of a seed (unduly coarse sorting). Below each tooth is a numbered receptacle, into which seeds of appropriate weight class are knocked by the operation of the sorter.

To operate the sorter, move the carriage clear of the balance pan. Take a seed from the hand-rest and seed reservoir with a pair of spoon-billed forceps, and place it on balance pan. Move the carriage along the track until a tooth knocks the seed into a receptacle. A tally-register may be added to record the total number of seeds classified.

The device has been used to classify, by 1-milligram intervals, several thousand Douglas-fir seed at a rate of 1000 seed per hour. A faster rotary type of sorter should be easy to construct.

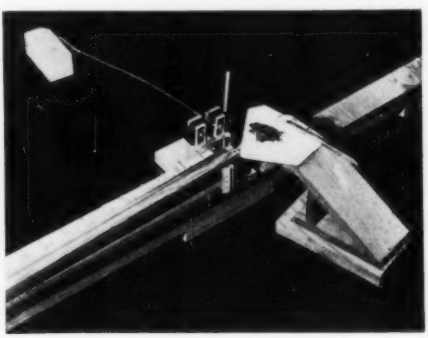

FIGURE 1. *Carriage with seed receptacles and unloading comb is at left end of travel on track, in position to actuate tally register. Damping vane on glass fiber is between upper poles of magnets. Pan is visible in front of right magnet. Block holding fiber in background.*

[1] Spurr, S. H. Effect of seed weight and seed origin on the early development of eastern white pine. J. Arnold Arboretum 25:467-480. 1944.

[2] Righter, F. I. Pinus: The relationship of seed size and seedling size to inherent vigor. J. For. 43:131-137. 1945.

[3] Gast. P. R. Studies on the development of conifers in raw humus III. The growth of Scots pine (*Pinus sylvestris* L.) seedlings in pot culture of different soils under varied radiation intensities. Statens Skogsförsöksanstalt., Meddel. 29:587-682. 1937.

[4] Sax, K. A simple device for weighing seeds. Bot. Gaz. 71:399. 1921.

A Technique for Determining Sex from Vegetative Buds of Quaking Aspen[1]

Note by G. M. Blake, R. L. Hossfeld, S. S. Pauley
Research Assistant and Professors, respectively
University of Minnesota

When studying putative sex associated characteristics in quaking aspen (*Populus tremuloides* Michx.) it is sometimes difficult to determine the sex of a tree because of the immaturity or complete absence of flower buds. This note reports a method of determining sex of quaking aspen by paper partition chromatography of extracts of vegetative buds in sexually mature plants.

Experimental Technique

Vegetative buds were collected on March 26, 1960, from 20 seedling-origin trees of a native population of quaking aspen near Coon Rapids, Minnesota. The sex of the ten male and ten female trees was determined by flower bud examination. One gm samples of vegetative buds were macerated in individual glass vials containing ten ml of 95% ethanol, and allowed to stand for one week. Aliquots of the extracts were spotted on Whatman #1 filter paper (18¼ in x 22½ in), placed in a chromatographing cabinet, and allowed to equilibrate in a saturated atmosphere containing ammonium hydroxide, secondary butyl alcohol, and water. The chromatograms were developed[2] by descending irrigation using secondary butyl alcohol equilibrated with water as the irrigating solvent. When the solvent front approached the bottom of the paper (approximately 24 hours), the chromatograms were removed and dried. The chromatograms were then sprayed with a 2% aqueous solution of sodium carbonate and again dried. Treatment with sodium carbonate caused the appearance of characteristically fluorescent spots in the chromatograms when observed under ultraviolet light.

Results

Figure 1 is a tracing of typical chromatograms of representative male and female bud extracts. Only those spots representing the characteristic differences have been included. Chemical differences are distinctly observable, especially the light green spot of the male and the brilliant orange of the female bud extracts. Al-

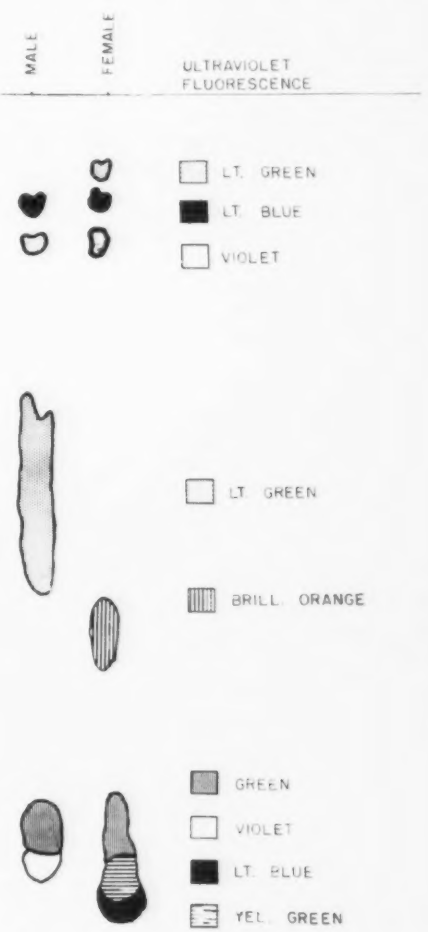

FIGURE 1. *Representative chromatogram of vegetative bud extracts from typical male and female quaking aspen.*

[1]This study was made possible by a grant from Wood Conversion Foundation of Cloquet, Minnesota. Published as a Scientific Journal Series Paper No. 4465 of the Minnesota Agricultural Experiment Station.

[2]Oberg, J. C., R. L. Hossfeld, and F. H. Kaufert, 1956 Fluorescent materials associated with discoloration in aspen. Tappi, Vol. 39, 7:470-471.

though the identities of the chemical compounds are as yet unknown, the differences between male and female trees in the present sample can be easily recognized by this technique. Deviations from these typical chromatograms were observed in one male and one female. Both were similar, however, to chromatograms prepared from buds taken from known hermaphrodites. Work is continuing in order to expand these findings, and a more complete report will be published in the near future.

Southern Forest Soils: 8th Annual Forestry Symposium

Edited by Paul Y. Burns. 132 pp. Illus. Louisiana State University Press, Baton Rouge. 1960. $4.

Review by W. E. McQuilkin
Northeastern Forest Experiment Station
Forest Service, U. S. Department of Agriculture

Beginning in 1952, the School of Forestry of Louisiana State University each year has sponsored a symposium on a different forestry theme. Southern forest soils was the 1959 theme of the 8th Symposium and the 15 papers presented there make up the content of this book.

The collected papers of a symposium, each by a different author, inevitably result in a somewhat disjointed book. However, the program chairman and editor for *Southern Forest Soils* did a masterly job of selecting topics and of controlling the general content and scope of each article. The 15 papers blend into a remarkably coherent whole. With one exception (Physiological Relationships of Soils to Forest Growth: Research Implementation, by McDermott and Fletcher), which disgresses a bit, the papers all hew close to soils and soil-related subjects, and are arranged in a well-chosen, logical sequence.

The 15 papers fall into three general groups:

(1) Descriptive—first 4 papers. These comprise discussions of the physical properties of southern forest soils by physiographic regions, of their hydrologic properties, and of soil moisture utilization by southern forests. The above-noted paper by McDermott and Fletcher is included here; it is an interesting but somewhat tangential discussion that touches upon physiological relationships of forest soils, but is oriented more toward the training of forest researchers.

(2) Site evaluation—6 papers. These include a description of the Soil Conservation Service approach to "soil interpretations for wood crop production," and 5 papers on different facets of soil-site studies and applications. The last paper of this group is a summary of the present status of soil-site information in the South by T. S. Coile who, with Professor F. X. Schumacher, originally developed the regression analysis method of correlating soil-site factors with site index. Coile also commented on the preceding papers; he took issue particularly with the Soil Conservation Service Soil Survey practice of attempting to assign average site index values to soil types.

(3) Measures for increasing natural soil productivity—5 papers. Included here are discussions of possible uses of fertilizers, irrigation, and drainage in southern forestry. The final paper is a thought-provoking exposition by C. E. Ostrom on the potentialities for improving forest growth. Using a recent book (*The Forest Area of the World and Its Potential Productivity*, by Sten Paterson of Sweden) as a springboard, Ostrom developed the thesis that, with genetically improved plant materials and intensive culture, 500 cubic feet per acre per year could be grown on the best sites in the South, and 350 cubic feet could be grown over broader areas.

This little book can be highly recommended, both as an account of recent accomplishments, and as a revelation of opportunities for further advances in understanding and evaluating the relationships between soil-site properties and tree growth. To southern forest managers it should open challenging vistas on the possibilities of increasing timber production through more intensive application of what now is known about southern forest soils.

Experimental Design and Analysis in Forest Research

By J. N. R. Jeffers. Almqvist and Wiksell, Stockholm, Sweden, 1960.

Review by James G. Osborne
Forest Service, U. S. Department of Agriculture

This book was issued by the permanent committee of the International Union of Forest Research Organizations. The framework and impetus for its issuance are contained in the first paragraph of the foreword: "A sound technique in experimenting is essential to the success of forest research in all parts of the world. This has long been recognized by the Union. Modern developments in this field have placed in the hands of research workers a whole range of new methods which enable them to design their experiments with economy, while the application of statistics allows them to obtain from these experiments much more information and information of much greater precision."

The author, J. N. R. Jeffers, is a member of the Forestry Commission, Alice Holt Research Station, Farnham. He sets the stage for his treatment of the subject in the final paragraph of his introduction where he states, "This bulletin is intended merely to make statistical methods more available to foresters engaged in research, and statisticians will find it has little new to say about the methods. They will also find the demonstrations of the methods by examples tedious compared with the symbolic and formalized notation to which they are accustomed." He explicitly exempts two subjects which he indicates are integral parts of scientific experimentation. These are: (1) the formulation of the objects of the experiment, the definition of the treatments, and the selection of hypotheses for testing; (2) the measurements of experimental material, from which the results of the experiment are calculated.

The book consists of eight chapters with a total of only 143 pages of text followed by four appendices. The latter include: I. Working sheets for the analysis of experiments, II. References, III. Shortened forms of statistical tables, and IV. Glossary of statistical terms in English, French, and German. Appendix III includes a frequently used table of mean values of the ratio of the range to the standard deviation, abbreviated tables of F and t, values of correlation coefficients and limiting values of Chi-square for probabilities of .05 and .01. Also included are tables for angular transformations and the transformation to probits.

After a short (8 page) chapter on experimental design the author launches into his longest chapter "Analysis of Experiments." This chapter which contains almost one-third of the text gives relatively extended treatment to randomized block experiments, latin-square, factorial, and split-plot experiments, with short treatments of the analysis of balanced incomplete block experiments, combination of experiments carried out in different sites and different years, and missing plots. This is followed by a short chapter on the use of transformations in the analysis of variance. Other chapters include Chi-square and the analysis of attributes, sampling, regression and correlation, the analysis of covariance, and presentation of the results of experiments.

In his discusisons of the analysis of experiments the author follows a rather consistent pattern of giving first a description or the nature of the experiment, next a preliminary analysis using estimates of the standard deviations got from the range, next if warranted, the detailed analysis using calculated standard deviations, and finally tests of significance. The reviewer is somewhat disturbed with the author's emphasis on preliminary analyses based on ranges of values. It may be that in some countries where desk calculators are in short supply such short cut approximations are warranted. In the United States, however, this condition does not exist and it seems a poor allocation of effort to run any risk of losing information which may be obtained from costly field data to save a few minutes of computational time. In the cases cited the author obtains estimates of the standard deviation closely in accord with those computed but we note that generally in such cases the blocks mean square is close in value to the error mean square. This is not typical and if there were very large differences among blocks, in contrast to that among treatment effects, one might easily discard experimental data of real

value simply because the range of values within a treatment from block to block might lead to a substantial overestimate of the experimental error.

The coverage in this short book is extremely extensive from the point of view of the number of techniques and concepts discussed. The author has been able to achieve this, and also to give the reader pertinent and sound advice and warnings concerning the uses of the techniques, by adhering closely to his general scheme of presenting the methods principally without proofs but with intuitive appeal. He has had to achieve this brevity by cutting somewhere and generally he accomplishes this end by referring to textbooks listed in Appendix II when either the complexity of the theory, or the length of the development necessary to achieve satisfactory presentation, become too great. For example, curvilinear regression is covered with 12 lines including a reference to Snedecor. Calculation by use of orthogonal polynomials also requires only 12 lines including references to five texts, and the calculation of multiple regression requires less than a page.

The author's writing shows him to be a well-trained and experienced statistician and consultant and his Chapter 8, "Presentation of Results of Experiments," contains much sound advice on scientific investigation and reporting.

Unfortunately, there are a number of typographical errors but none of these should cause any serious difficulty since generally they are evident. The conclusion of the reviewer is that Jeffers has done a splendid job of selecting the statistical techniques most likely to be useful to forest research workers who have not had formal training in statistical methods and experimental design and if they read his discussions, explanations, and warnings carefully they are not likely to misuse the methods. It thus should be a good reference book and occupy a prominent place on the forest research worker's shelf of reference manuals.

The Fundamentals of Plant Use for Soil Stabilization

Grundlagen der Gruenverbauung. By H. M. Schiechtl, 1958. Mitteilungen der Forstlichen Bundes-Versuchsanstalt. Mariabrunn, Austria, Heft 55. 273 pp. No price indicated.

Review by B. H. Heede
Rocky Mountain Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture

Based on 10 years of observation and experiment, this book summarizes the use of plants for soil stabilization.

Although the author confines his observations and experiments to a limited part of the Alps he cites use of plants in other regions for comparison including that in connection with the Autobahn construction in Germany, afforestation on the Etna Mountain in Sicily, and erosion control in Switzerland, France, and the United States.

Control of erosion is a very old practice in Europe. Masonry and concrete control structures were formerly emphasized. Since World War II the trend has been toward control by the use of vegetation coinciding with the change in Middle European forestry from artificially established mono-forests to forests established according to biological and ecological principles.

High construction and maintenance costs limited the application of mechanical struc-

tures. Moreover, at many locations mechanical measures could not be applied because of unfavorable topography or difficult transportation. Under such conditions control only by vegetation was possible. Planting stock may be obtained close at hand and is easy to transport.

The book has four sections: (1) selection of plant species suitable for soil stabilization, (2) construction methods used in vegetal soil stabilization projects, (3) maintenance of vegetal soil stabilization projects, and (4) planting methods.

The author bases the selection of plant species for erosion control on nine factors. These are: objective of the project, ecology of the location, regenerative ability of the plant, resistance to mechanical strain, growing potential of the plant and its potential to form stands, ability of the plant to stabilize soil, tensile strength of roots, growth rate, and utility and aesthetic value.

Plant communities resulting from artificial rehabilitation of eroded areas are: meadow, brushland, and forests. Different methods of artificial revegetation are possible. Pioneer species may be selected to start the slow process of natural plant succession, or a managed subclimax vegetation may be established through plantings. Establishment of a climax vegetation although desirable often is not feasible because of local ecological changes that have already taken place. In such cases a pioneer plant or a pioneer plant community is first selected to prepare the soil and micro-climate so that a permanent vegetative cover can later be established either artificially or naturally.

The author diagrams successions that lead to specific climax plant communities on the basis of which he extends the classification of unstable slopes initiated by Raschendorfer.[1]

Detailed root diagrams are presented and techniques of rehabilitation are discussed. It was found that cuttings planted horizontally produced a more vigorous plant within a shorter period of time than when planted vertically. Cuttings stuck vertically into the ground gave good results where the planting depth corresponded to $^3/_4$ to $^4/_5$ the length of the cuttings (16 to 20 inches).

A type of wattling, called brush layers (Buschlagen) by the author, is of special interest. Ditches 1.5 to 3 feet wide with the floor sloping gently into the hillside are dug on the contour. Minimum distance between ditches is 6 feet. Ditch depth varies from 1.5 to 2.5 feet, depending on the length of the cuttings. The cuttings are placed crosswise in the ditch so that ¾ of the length is above ground surface. The ditch is then filled with earth. Work starts at the bottom of a hillside and proceeds uphill in order to use the excavation from above as fill material for the ditch below. This system has the advantage over older wattling methods in that the cuttings will resist falling rocks, sliding snow, and avalanches as soon as the soil settles. When rooted the cuttings will tolerate a yearly soil deposition of 8 to 12 inches.

With its many pictures, tables, graphs, and bibliography this practical reference, if translated into English, would be a valuable guide for erosion control work in America.

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[1]Raschendorfer, I. "Blaikentypen in den Tiroler Alpen," Vereinszeitschr. der Dipl.-Ing. der Wildbachverbauung, Heft 5, 1954.

Growth and Yields of Natural Stands of the Southern Pines

By F. X. Schumacher and T. S. Coile, T. S. Coile, Inc., Durham, N. C. 115 pp., illus. 1960. $6.

Review by Kenneth D. Ware
Northeastern Forest Experiment Station
Forest Service, U. S. Department of Agriculture

The main purpose of this compact volume is to present information—and a methodology for using it—that will enable prediction of future stand variables. It will be useful both to forest managers in the South, for the storehouse of valuable information it contains, and to mensurationists generally, for the interesting technique of yield prediction. The authors, Schumacher and Coile, need no introduction, being of eminent reputation in the fields of mensuration and soil-site productivity.

In the words of the authors its "tables and graphs . . . summarize the results of detailed investigations of natural even-aged stands of six species of southern pine from the viewpoint of stand development." The information is given in the form of tables and graphs prepared from or depicting least squares multiple-regression equations fitted to sample plot data, separately for the following species of pine, the number of sample plots constituting the basic data being given in parentheses: (1) *Pinus taeda* L. (420 plots); (2) *Pinus elliottii* Engelm. (231); (3) *Pinus palustris* Mill. (368); (4) *Pinus echinata* Mill. (74); (5) *Pinus serotina* Michx. (130); (6) *Pinus clausa* (Chapm.) Vasey (54).

Yield tables are first presented for well-stocked, natural, even-aged stands of each species. The authors use "well-stocked" to mean not the "normal stocking," but a more realistic stocking standard based on an average of the sample plots. The plots were taken for measurement only if they "contained the characteristic distribution of stem diameters for age and site class" . . . and if "past cutting had [no] apparent effect on stand structure or crown canopy." The "stocking percentage," defined as the fully utilized area that the stand should require relative to the area it actually occupies, for "well-stocked" stands is then 100 percent, which is the average stocking percentage for the data.

A cautionary remark of the authors is worth repeating, *viz.*, that these yield tables "are not suitable for growth prediction unless, perchance, the actual stands with which they are compared are equally well stocked." The second part of the work, however, contains graphs that can be used to predict future yield from the usual stand data collected during timber inventory, whatever the stocking condition of the stands in question.

How to use these graphs is explained clearly and concisely. For an example, a case-study problem is carried through in detail for a 50,000-acre property in Alabama.

The derivation of the graphs, though they are simple to apply, involves some sophisticated and interesting mensurational methodology. The fundamental plot variables are age, height of dominant stand, number of trees, basal area, and average stem diameter. The derived variables are volume in cubic feet, pulpwood volume in standard cords, and volume in board-feet Scribner in trees of sawlog size.

The regression equations on which the graphs and tables are based, along with brief discussions of them, are given in an appendix. This appendix will be of interest to mensurationists. One of the unique features is the equation for "stocking percentage" as a function of basal area per acre, height of dominant stand, and age of stand. It is unfortunate that no measure of the goodness of fit or residual error of any of these relations is included.

This slim volume, of great practical value to foresters throughout the range of the southern pines, contains a wealth of information far out of proportion to its size. It brings together for the first time into a single source, a unified summary of data and methodology for prediction of growth and yield for the important southern pines.

A Suggested Technique for Estimating the Future Price of Eastern White Pine Stumpage

BY
I. IRVING HOLLAND

THE VERY SUBSTANTIAL difficulties involved in trying to estimate the future price of any commodity, even over a short period of time, are generally recognized. When very long-time projections must be made, the usual situation where timber prices are concerned, the inherent difficulties are greatly magnified. Price results from the complex interaction of numerous factors of market demand and supply. Our present understanding of these complex supply-demand relationships for a great many commodities is incomplete, and accurate price projection techniques are not well developed.

Recognizing that an attempt to estimate future timber prices may result only in the roughest of approximations at best, one might legitimately question the desirability of such a hazardous undertaking. In answer, it should be pointed out that price estimation is but one part of the much larger problem of how to make rational comparisons of possible economic alternatives. Timber growing may be one of these. In the final analysis determination of economic feasibility involves examination of cost-return possibilities, and the ultimate managerial decision will rest, in whole or in part, on comparisons of estimated net returns from these economic alternatives.

The rational determination of the economic feasibility of timber growing should depend upon the best available estimates of future market values and supply possibilities under varying degrees of forest management and costs. Whether or not one is justified in deliberately attempting to estimate future timber prices as well as costs depends upon whether or not he believes forest management can be better guided by such economic considerations. Of course, many managerial decisions actually do rest upon comparisons of estimated costs and returns, but very frequently these are little more than guesses. If systematic, quantitative analysis of future economic possibilities can provide helpful guides to forest management, even though approximate, then they are worthy of consideration and development despite the difficulties involved.

Objectives

This analysis has two principal objectives: (1) to develop a technique for estimating the future price of stumpage; (2) to demonstrate the technique by estimating the prices of three quality grades of eastern white pine stumpage for the Lake States region in the year 2010, and also the future stumpage prices of two closely related species, western white pine and sugar pine. The particular market period with which we are concerned is 1980-2040, the period during which most of the Lake States region's young white pine stands will become

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mature. Timber uses and prices over the proposed market period will, of course, change, even as they will change between the present and 1980. However, to avoid unwarranted refinement, probable markets during the middle of this period will be stressed and the year 2010 is used as the basis for all projections of timber use, prices, and other relevant trends.

At least two other related objectives are also involved in the process of technique development. These are: (1) estimation of the most probable future uses and markets for white pine in general and eastern white pine in particular and (2) determination of what these probable future uses imply as to the qualities of timber that will be required.

General Method of Approach

Stumpage price may be estimated in several ways, the estimating models used differing primarily in the degree of their complexities. For instance, one could estimate future stumpage price merely by arbitrarily assuming some percentage increase over a base price. Or, one could relate past stumpage prices to time and derive a simple mathematical prediction equation; future price would then be estimated by extrapolation to the desired target year; in this case the year 2010. Another model might relate stumpage price to consumption and perhaps to other pertinent variables; the estimated price would be based on the assumption of the most probable levels of the "independent variables." More logically, future stumpage price might be estimated by empirically describing stumpage demand and supply functions, projecting these into the target year and estimating future price through their intersection.[1] Other refinements are, of course, possible providing the necessary data are available.

[1]For a more complete discussion of an application of this technique to the problem of estimating future price and consumption of sugar pine stumpage, see Vaux, H. J. Economics of the young-growth sugar pine resource. California Agric. Expt. Sta. Bull. 738. 1954.

Theoretically, it may be agreed that price and consumption of economic commodities are generated in the market through the interaction of forces of demand and supply. But it is difficult to devise a quantitative price estimating model which faithfully incorporates the basic notions of the market equilibrium solution. For any commodity requiring an estimate of future price (or consumption) by this approach, we would need to describe mathematically the demand-supply relationships involved; and then project these functions into the target period either as continuing reflections of past relations or as appropriately modified to reflect anticipated changes. In addition, in order to describe the demand for *some* commodities, one would also need to describe supply at the same time. Lumber may be such a commodity, for it appears that price and production of lumber are generated simultaneously and continuously in the market.

Supply-demand relations may be very complex and difficult to describe. As an example, we may cite eastern white pine lumber which has a number of good substitutes in use. The prices of eastern white pine and its substitutes are interrelated, and all are generated simultaneously and continuously over time. In this case it is difficult to estimate the price of eastern white pine lumber without somehow being able, at the same time, to consider the several demand (and supply) interrelations involved in the pricing of its several substitutes.

Complex estimating models can be specified, however, and fitted where suitable data are available. It is firmly believed that the development of better prediction models must involve continual effort to describe and mathematically to fit complex economic relations wherever this can be done. Such a procedure was not considered feasible in the present study primarily because there is a lack of suitable required data needed in the quantification of the relationships.

Is it possible to estimate approximately the future price of eastern white pine stumpage without undertaking the mathematical description of a complex economic model? Can we perhaps devise a simpler method for doing the job, one which still considers *at least indirectly* the probable future demand and supply conditions for this species within what will very likely remain a complex, competitive market structure? It is believed that useful estimates can be made within these restrictions.

The price estimating model used in the analysis rests upon the idea that the market demand for the several kinds of white pine lumber and stumpage, including eastern white pine, are very "elastic." A commodity with an elastic demand is one which most frequently has a number of close substitutes in use. Over its usual range of prices the demand curve for such a commodity would tend to be "flat."[2]

Along such curves changes in sales, when prices change, are greater in percent than the changes in price; i.e., price elasticities over a considerable part of the curve may be high. Conversely, with such demands percentage changes in price are relatively small when supply is modified by a given percentage and other factors remain unchanged; price flexibilities (the reciprocals of price elasticities) are low. By way of an example, a perfectly elastic demand curve would be represented by a horizontal line, and the height of this line would be synonymous with price level. Price flexibility at any point on such a curve would be zero.

The demand for a particular commodity is rarely perfectly elastic over its entire range, although within a certain price range it might approach this condition. Furthermore, demands for certain commodities even over limited ranges of price may not be completely elastic, even though they have a number of close substitutes in use. For example, the demand for low-grade lumber is probably more elastic than for high-grade lumber because the lower grade material has in fact more substitutes. In many uses high-grade lumber can be used in place of low-grade lumber, but not vice versa. Nevertheless, the presence of lower grade lumber which can be satisfactorily substituted for the higher grades in some uses tends also to reduce the elasticity of the higher grades.

Along this same line a commodity with good substitutes may enjoy a premium price in a certain market and its demand may be somewhat less elastic than demands for its susbtitutes if the substitutes are produced outside the particular market area and must bear costs of transportation. This would seem to explain the premium price paid for certain grades of eastern white pine lumber in eastern markets, even though western species of similar quality are shipped into these markets in substantial volume.

Finally, demand for a particular kind of lumber may differ somewhat from the demand for the raw material stumpage. In general the demand for lumber tends to be more elastic than demand for stumpage. Lumber can be shipped into a market area

[2]Demand in this discussion is market demand and is defined as a net negative relation between amounts of a commodity which would be sold and their corresponding prices, all other demand factors such as disposable income, consumer preferences, prices of closely related commodities, etc., remaining constant. A coefficient of price elasticity is a negative ratio of the percentage change in sales associated with a percentage change in price and varies from point to point along a demand curve. A coefficient greater than 1.0 represents elastic demand at the point. A coefficient less than 1.0 represents an inelastic demand at the point. A point of unitary elasticity would be represented by a coefficient of exactly 1.0. Slope or flatness and elasticity should not be confused. Actually a straight line demand curve with considerable slope will be elastic at those points nearer the price axis (at higher prices), unitary elastic at the halfway point, and inelastic at points nearer the quantity axis (at lower prices). Elasticity coefficients computed for points along demand curves of very little slope are usually greater than 1.0, however.

from several sources, but stumpage supplies are much more fixed. Processors of eastern white pine stumpage, for example, do not process western white or sugar pine stumpage. Over the long run, however, differences in lumber and stumpage demands may be less because the total volume and distribution of timber can be significantly modified.

We do not propose that white pine lumber or stumpage demands are or will be perfectly elastic. But it is believed that over a sufficiently wide range of production possibilities these curves will approximate horizontal straight lines. If the levels of such lines can be estimated, they will serve to define future price levels within suitable limits for purposes of present production decisions. Furthermore, if future demands for stumpage are very elastic (price flexibilities are low), then price estimates can be made without simultaneous estimates of supply possibilities; the problem of price estimation is thus simplified. Potential supply possibilities and costs, of course, can still be compared to the estimated stumpage values in determining the economic feasibility of timber growing under various management alternatives.

Carrying through of the estimating procedure will involve several steps: (1) the examination of past trends in the more important uses for the white pines to show that all have been used for similar purposes, to point out the relationship between lumber use and quality requirements, and to evaluate the prospects for future white pine lumber use and quality needs; (2) an analysis of the past price and consumption behavior of these species (plus southern pine) to test further the hypothesis that the white pines and ponderosa pine have been good substitutes and that their demands have probably thus been relatively elastic; (3) the definition of the three kinds of stumpage for which price estimates are to be made; (4) the development of a specific technique for estimating stumpage prices consistent with the assumed characteristics of demand, which uses an estimate of the Bureau of Labor Statistics' wholesale lumber price index level in the target year in conjunction with future estimates of the ratios of white pine lumber prices to this index and estimates of the ratios of white pine stumpage prices to lumber prices; (5) the use of this technique, in the estimation of stumpage prices for Lake States eastern white pine of high, medium, and low quality, and for sugar pine and western white pine in the year 2010.

Past and Probable Trends in the Use of White Pine Lumber

Future market demands for eastern and western white pine timbers will depend upon the market prospects for white pine products, particularly lumber. Recent data are not available, but in 1948, according to the U. S. Forest Service (1951), roughly 40 percent of all eastern white pine lumber was used in light construction for sheathing, sub-flooring, and for other structural elements where load-bearing strength was not essential. An equal amount was used for the packaging and crating of industrial and agricultural products. The remainder, something under 20 percent, went into the manufacture of a multitude of products frequently referred to as "specialty products." This group includes such items as sash, doors, and other millwork, patterns and flasks, boot and shoe findings, furniture and fixtures, toys, athletic equipment, maps and shade rollers, woodenware and novelties, ship and boat building, scientific instruments, and prefabricated structures.

In considering future production of eastern white pine, particularly where expenditures for forest management and protection will be involved, the question may be asked, "How important is the use of eastern white pine and, for that matter, all the white pines put together?" In 1948, total production of white pine lumber amounted to 1.6 billion board feet, about 5 percent of all softwood lumber. Eastern white pine accounted for about 3 percent. On the basis of relative importance in total

softwood lumber production, it is obvious that the white pines have not been extremely important. In consumption for certain uses, however, the white pines have been relatively more important. Of all softwood lumber used for containers, for example the white pines accounted for just under 20 percent; and for specialty products including millwork, about 10 percent in this same year. Of these, eastern white pine accounted for 17 percent and 5 percent, respectively. The question, then, is one of relative importance in particular uses.

In the discussion of white pine lumber consumption, reference will be made to "low-," "medium-," and 'high"-quality lumber. As used here, low quality refers to #4 common or lower grade material. The term high quality refers to lumber which grades #2 common or higher; medium-quality lumber is #3 common material. In the discussion to follow the average quality of western white pine or sugar pine lumber is also considered to be relatively higher than New England eastern white pine lumber, because the grade recoveries of the western timber run much more heavily to the upper commons, shop, and select grades.

White pine lumber for construction. Estimates of lumber consumption by principal use and by species are unavailable, but Figure 1 shows annual production of eastern

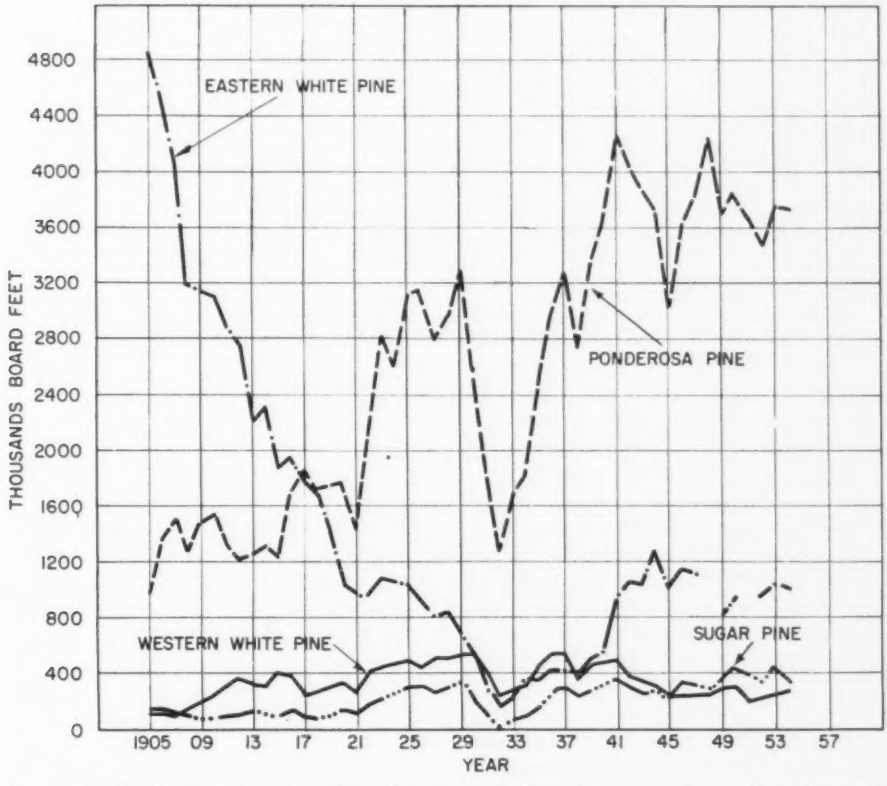

FIGURE 1. *Production of eastern white pine, western white pine, sugar pine, and ponderosa pine lumber, 1905-1954.*

white pine, western white pine, sugar pine, and ponderosa pine lumber from 1905 to 1954 as estimated by Steer (1948), the Forest Service, and the Bureau of the Census. These data are published in "Historical Forestry Statistics of the U. S." (U. S. Forest Service, 1958). The dominant past position of eastern white pine lumber is readily apparent. After World War I, ponderosa pine became the most important of this species group. Sugar pine lumber production has steadily increased over time, while production of western white pine appears to have stabilized in recent years at a level considerably lower than before World War I.

There are no measured data on volumes going into construction. These must be derived by subtracting from total lumber production the volumes used for manufactured products including containers. The source of the latter information is the several "lumber used in manufacturing" studies undertaken by the Forest Service covering the periods 1909-13, 1928, 1933, 1940, and 1948. These studies are not directly comparable unless adjustments are made for differences in industry and item coverage. The discussion to follow is based on fully adjusted data; millwork is included with specialty products. Because planning mill products could not be separated from millwork in the 1909-13 data, this particular survey is not used in the analysis of trends in wood used for specialty products. All data are included in the discussion on trends of wood used for containers, however.

In 1928, white pine lumber used for construction accounted for about 3 or 4 percent of all softwood lumber so used; in 1933, only 1 percent; in 1940, between 4 and 5 percent; and in 1948, 4 percent. The proportion of total white pine production going into construction has varied from around 25 percent in 1928 to over 50 percent in 1940 and 1948. Although there are no recent data, it is likely that a substantial proportion of all white pine production is currently being used for construction. Low-grade eastern white pine lumber cut from second-growth timber makes up most of this material.

Except for knotty pine paneling consisting mostly of #3 common and selected #4 common boards, most eastern white pine construction material comes from #3, #4, and #5 common lumber. According to a recent estimate[3] average eastern white pine outturns are selects 3 percent, #1 and #2 common 12 percent, #3 common 35 percent, and #4 common 50 percent. This is the kind of lumber which is now being cut from second-growth unmanaged stands of white pine in the Northeast and Middle Atlantic states.

Demand (and price) for this material will be relatively low compared to higher quality lumber despite the fact that prospects for future construction are generally viewed as bright. Construction grade lumber produced from ponderosa pine, Douglas-fir, southern pine, and other suitable softwood species will probably continue to dominate this market. Thus, even if the demand for relatively low-quality eastern white pine lumber increases as the economy grows, it is not likely that the future market position of this lumber will be materially changed.

White pine lumber for containers. For containers the white pines have occupied a more prominent position. In the 20-year period between 1928 and 1948 just under 20 percent of all softwood lumber used for containers was white pine; almost all of this was low-grade eastern white pine. Ponderosa pine made up over 40 percent of all softwood container material in this same period.

As is generally known, use of lumber for containers has decreased steadily in the last 25 years, except during World War II, when large quantities of lumber were needed in the overseas shipment of war material. Fiberboard containers, veneer

[3]Estimates originate with the Northeastern Lumber Manufacturers Association, New York, N. Y.

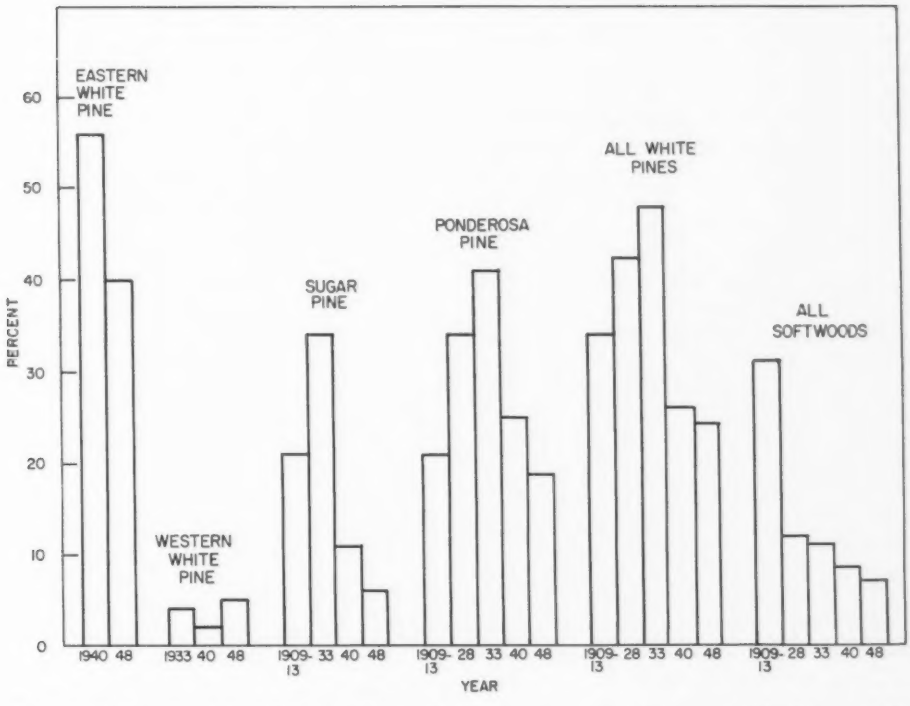

FIGURE 2. *Percent of total lumber supply used for containers, selected years, 1909-13 to 1948.*

boxes and crates, and combination lumber-veneer and lumber-fiberboard containers have cut deeply into the container lumber market. The principal reason for the shift to non-lumber containers is that both fiber and wirebound containers are cheaper than lumber boxes. Moreover, they are lighter in weight, thus lessening shipping charges.

Some indications of trends in softwood lumber use for containers is shown in Figure 2. Within the limits of the available data, it appears that after 1933 the proportions of total lumber supply used in container manufacture declined for eastern white pine, sugar pine, ponderosa pine, and all softwoods considered together. Use of western white pine for containers does not seem to have increased or decreased significantly. Actually, only about 5 percent of western white pine lumber goes into containers; on a volume basis only about 13 million board feet were used in 1948 compared to almost 18 million board feet of sugar pine, 363 million feet of eastern white pine, 829 million board feet of ponderosa pine, and over 2 billion feet of all softwoods combined.

Fiber packing cases are well adapted to the modern trend toward prepacked commodities, and they provide adequate protection in the shipment of agricultural and industrial goods where cases are not piled one atop the other to any great extent. Although lumber will continue to be used in the shipment (especially overseas shipment) of certain heavy, odd-shaped, delicate, or fragile items, it is quite likely that the use of lumber in containers will continue to decrease relative to use of all container materials. It is probable that even-

tually, the nailed wooden container may be confined to those uses in which substitute containers cannot be used at all. This is even more likely to be the case if, as expected, the price of lumber continues to increase relative to the price of fiberboard.

With a continued expected decline in the use of lumber for containers, the prospects of marketing low- to medium-grade white pine lumber are further decreased. This does not mean that low-grade white pine lumber will necessarily be less in demand in the future than today, for we anticipate a susbtantial increase in demands for all grades of lumber. What it does mean is that this material may have to compete in low-grade uses even more strongly than it does today with the other softwoods produced in larger volume.

White pine lumber for specialty products. In 1948, about 446 million board feet of white pine lumber was used for specialty products including millwork. Of this total, eastern white pine accounted for 220 million board feet; western white pine, 132 million; and sugar pine, 94 million. In terms of total softwood lumber used for specialty products, the white pines accounted for 10 percent; ponderosa pine accounted for about 32 percent; Douglas-fir, 33 percent; southern pine, 20 percent; and eastern white pine, 5 percent. Douglas-fir and southern pine are also widely used for millwork, flooring, and car construction.

Specialty products are generally made from high-quality lumber. In 1948, millwork accounted for 37 percent of all eastern white pine lumber used for manufactured products other than containers. National averages are not available, but according to a wood-use study conducted in New York by Deckert and Hoyle (1956), almost 50 percent of the eastern white pine lumber used for millwork in 1954 was #1 common or better grade and 84 percent #2 common or better; 26 percent was of D and better select. Almost 75 percent of the ponderosa pine and sugar pine and 95 percent of western white pine so used was #2 common or better grades.

Table 1 shows the volumes of white pine and ponderosa pine used in the manufacture of specialty products and the proportions each constituted of all white pine lumber and all softwood lumber used in these industries in 1948. It is important to note that although the white pines together made up only about 10 percent of total softwood lumber used in manufacture in 1948, they accounted for much more than 10 percent in every use indicated in the

TABLE 1. Principal manufacturing uses and importance of the white pines and ponderosa pine, 1948.

	Eastern white pine		Sugar pine		Western white pine		Total white pine		Ponderosa pine	
	Volume used MM bd. ft.	Percent total white pine	Volume used MM bd. ft.	Percent total white pine	Volume used MM bd. ft.	Percent total white pine	Volume used MM bd. ft.	Percent total softwood	Volume used MM bd. ft.	Percent total softwood
Millwork[1]	38.6	23.4	66.9	40.6	59.2	36.0	164.7	8.4	1,135.5	57.9
Patterns & flasks	41.9	64.3	19.5	29.9	3.8	5.8	65.2	71.8	7.4	8.1
Boot & shoe findings	30.3	97.7	0.4	1.3	0.3	1.0	31.0	95.6	1.4	4.3
Furniture & fixtures	36.1	77.1	1.2	2.6	9.5	20.3	46.8	11.9	120.4	30.7
Map & shade rollers	6.7	55.4	0.3	2.5	5.1	42.1	12.1	58.4	6.1	29.6
Matches	0	0	0	0	34.2	100.0	34.2	98.0	0.7	2.0
Ships & boats	4.9	59.0	0.2	2.4	3.2	38.6	8.3	13.2	1.6	2.6
Toys	9.4	88.7	0.3	2.8	0.9	8.5	10.6	40.2	14.0	53.4
Other	52.2	71.5	4.8	6.6	16.0	21.9	73.0	4.1	127.1	7.1
Total	220.1	49.4	93.6	21.0	132.2	29.6	445.9	10.1	1,414.2	32.1

[1]Includes flooring.

Source: U. S. Dept. Agric., Forest Service, Wood Used in Manufacture, 1948. Forest Resource Report No. 2. Washington, D. C. 1951. Volumes include lumber used by industries manufacturing non-wood products.

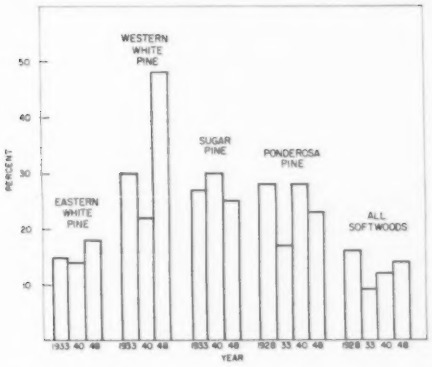

FIGURE 3. *Percent of total lumber supply used for specialty products, selected years 1928-1948.*

table but two. Except for millwork, furniture and fixtures, toys and miscellaneous items, the white pines were even more important than ponderosa pine. In some cases, as for patterns and flasks, boot and shoe findings, matches, and rollers, the preference for white pine is quite striking. Of the three white pines, eastern white pine was by far the most important.

Available data indicate that consumption of the white pines and ponderosa pine for specialty uses has increased over time. This is in contrast to trends in container use. Figure 3 shows the consumption of ponderosa pine, the white pines, and all softwood lumber expressed as a percentage of the total production of each of these kinds of lumber. Since 1933, all but sugar pine show an upward trend. Figure 4 indicates further that relative increases for eastern white pine and ponderosa pine have been quite remarkable. Use of eastern white pine increased almost 400 percent, while use of all softwoods rose only 235 percent. This increase for specialty products is even more striking in view of the fact that between 1933 and 1948, total production of eastern white pine lumber increased only 75 percent.

In view of the anticipated expansion in population and personal disposable income, the U. S. Forest Service (1958) estimates that potential lumber demand for specialty products may increase almost 60 percent over 1948 by the year 2000 (excluding millwork, containers, and lumber used for railroad car construction). By the year 2010, expected demand will be even higher. If the present preference for eastern white pine in specialty use is merely maintained, prospects for increased use are bright. One other development may operate to enhance the prospective demands for eastern white pine lumber, but especially for high- to medium-quality lumber. Population growth and industrial development in the western states are expected to continue at relatively high rates. For the Pacific Northwest, which includes Oregon, Washington, Idaho, and part of Montana, the Columbia Basin Inter-Agency Committee (1952) estimated that population should continue to increase more rapidly than the national population for a long time to come. The Bureau of the Census (1957) estimates that between 1955 and 1970, the Pacific Coast states' populations are projected to grow at almost twice the national average (51 percent compared to 27 perment); the Mountain States are to increase about 45 percent. Not only will the na-

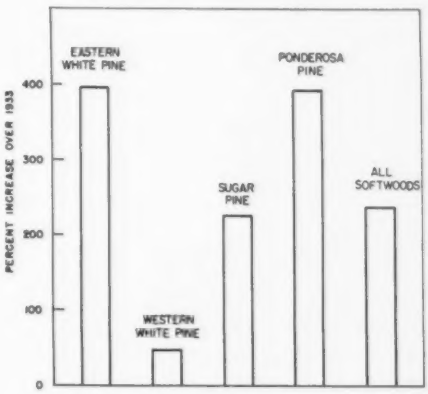

FIGURE 4. *Percentage increase in use of the white pine, ponderosa pine, and all softwoods. 1933 = 100.*

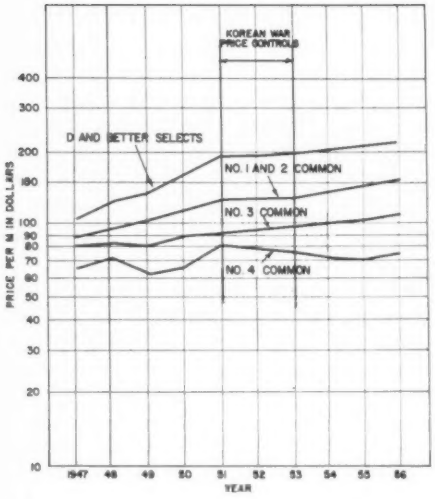

FIGURE 5. *Average wholesale price of eastern white pine lumber by grade, 1947-1956. Prices are for lumber delivered to Boston until April 1947. After 1947 prices are f.o.b. mill based on mid-point of price range for each grade as quoted by the Commercial Bulletin (Boston) and are averages for sizes 1 x 4, 1 x 5, and 1 x 6, 7, and 8.*

tion's demand for all timber products be greatly increased by our target period, but these demands will be proportionately larger in the western states than they are today. Despite the expected differences in regional population and industrial growth rates, however, the bulk of the nation's wood consumption will very likely continue to take place east of the Mississippi and north of the Ohio and Potomac rivers.

It is significant that remaining virgin stands of timber, including sugar pine, western white pine, and ponderosa pine, are found in the regions expected to grow the most rapidly, while the areas which could again produce eastern white pine in substantial quantity are located in or near the region expected to contain the bulk of the nation's population and industry. The western soft pines are expected to share in increased western regional demands for timber products generally and lumber especially. A possible effect would be materially to enhance the demand for eastern white pine in the large consuming centers of the East.

Some further indication of the present preferred position of better quality eastern white pine lumber in contrast to low-quality lumber is shown by the data in Figures 5 and 6. Figure 5 shows very strikingly the very large differentials in price between the selects and common grades. In 1956, the average price of D and better select grade lumber was about 275 percent greater than the price of #4 common, 85 percent greater than #3 common, and almost 40 percent greater than the price of #1 and #2 common lumber. The premium commanded by clear grades is obvious.

Figure 6 shows the same data plotted on semi-logarithmic paper in order that rates of change may be compared. Before the Korean conflict, the price of D and better selects rose more rapidly than any of the lower grades. After 1953, the prices of all the grades above #4 common have risen at about equal rates; these are the grades used most frequently in the manufacture of specialty products. The price of

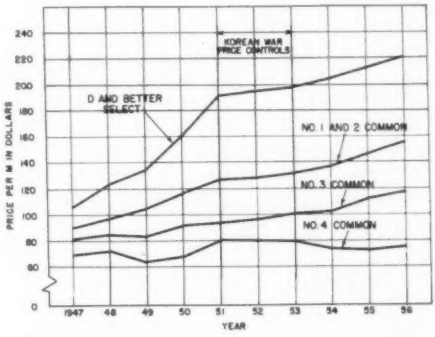

FIGURE 6. *Relative change in average wholesale price of eastern white pine lumber by grade, 1947-1956.*

#4 common, which is produced in very large volume, has been unstable and has risen very little since 1947. This is very largely a reflection of a continuation in the declining market for box lumber and increased competition from western softwoods in construction.

Analysis of White Pine Lumber Price and Consumption Behavior—a Rough Test of Substitution Relationships and Demand Elasticity

The preceding discussion points out that all the white pines and several other important western softwood timbers are used for similar purposes and are thus substitutes one for the other. A priori, one would expect their demands to be relatively elastic. Short of complex statistical analysis it is, of course, impossible to describe elasticity coefficients and to indicate how "elastic" one demand is as compared to another. However, if suitable data are available, it is possible to perform a simple statistical test, the results of which may suggest whether or not two commodities have actually behaved as substitutes. The immediate purpose is to demonstrate this test; to see if the past prices and consumption of the several white pines, ponderosa pine, Douglas-fir, and southern pine suggest competitive market behavior.

Conceptually, if two commodities are perfect complements, they will be used in some constant ratio of quantities; the ratio of their prices would not necessarily be constant, however. According to Schultz (1938), it is assumed by this test that if over some time period the ratios of the quantities consumed of two goods appear to have fluctuated relatively less than have the ratios of their prices, the two commodities have behaved as complements. On the other hand, if two goods are perfect substitutes, their prices will bear a constant ratio, there being no such restriction on the ratios of the quantities consumed of each. This actually tends to be so, for if at any time the ratio of their prices becomes other than the ratio at which one good could be substituted for the other, one of them would tend to be substituted to the exclusion of the other. Clearly, relatively small changes in the price of the substitute commodities would tend to be associated with relatively larger changes in the quantities sold of each, other factors remaining constant. It should be borne in mind that this is only a rough test of complementarity and it cannot be used to "prove" that two goods are either substitutes, complements, or independent in demand.

The statistic used in comparing the degree of ratio fluctuations is the coefficient of variation.[4] If in this comparison the coefficient of variation of the price ratios is greater than the coefficient of variation of the quantity ratios, the two goods are said to have been completing in demand. If the coefficient of variation of the price ratios is less than the corresponding coefficient of variation of the quantity ratios, the two goods are said to have behaved as substitutes.

Table 2 compares coefficients of variation of lumber price and production (which approximates consumption) for eastern white pine, western white pine, sugar pine, all white pines, ponderosa pine, Douglas-fir, and southern pine. An examination of the size of the resulting coefficients of variation suggests rather strongly that all three white pines have been good substitutes. Furthermore, the white pines considered together and ponderosa pine have also been very good susbtitutes. For the white pines and southern pine, the coefficients suggest a much poorer substitution relationship; with Douglas-fir, a stronger relationship.

The following tabulation lists the ratio of the coefficient of variation of quantities to the coefficient of variation of prices for each of the species combinations shown in Table 2:

[4]The coefficient of variation is calculated by dividing the standard deviations of a series by the mean of the series. In this case, for example, the standard deviation of the price ratios is divided by the mean price ratio. The coefficient of variation of the quantity ratios is similarly determined.

Kinds of timber	*Ratio*
All white pine vs. ponderosa pine	8.12
Eastern white pine vs. western white pine	5.98
Eastern white pine vs. sugar pine	4.96
Western white pine vs. sugar pine	3.63
All white pine vs. Douglas-fir	3.03
All white pine vs. southern pine	1.67

The white pines and southern pine are not generally considered to be good substitutes. Because of very different wood characteristics and widely differing volumes produced, these species actually do not compete strongly in use. The lowest figure in the tabulation (1.67) appears to bear this out and might represent the poorest of the substitution relationships shown in Table 2. By contrast all the other values in the above tabulation suggest much stronger relationships. Ponderosa pine lumber which is widely marketed in large volumes competes strongly with all the white pines in construction and container manufacture, as well as in the manufacture of specialty products. Evidence of this strong substitution relationship is indicated by the relatively large value of 8.12 in the tabulation. Also the white pines appear to be "good" substitutes among themselves. Although it was not done, it is almost certain that a comparison of coefficients of variation for each white pine species and ponderosa pine would also indicate strong substitution relationships. Even though they do not represent completely satisfactory criteria for measuring the closeness of substitution among the several species of white pine, these data do suggest that such relationships have been strong. If so, we may conclude that demands for these kinds of lumber and stumpage have probably been very elastic.

If the relationships carry into our target period without substantial modification, then the future price of a particular kind of lumber or stumpage will be determined primarily by demand factors. Thus the future price of eastern white pine lumber would not be greatly influenced by the volume produced or offered for sale but by modification of the level of demand through change in the availability of the substitute western lumbers. Trends in the species use pattern then would directly affect the size of a particular market and change in the overall demand for wood. Also with respect to eastern white pine stumpage, different prospective supplies of one grade or another which may be forthcoming in the target year (depending upon management decisions made today) will not in them-

TABLE 2. Substitution relationships among the white pines, ponderosa pine, southern pine, and Douglas-fir, 1915-1943.

Kinds of lumber	Quantity or production ratios			Price ratios		
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
Eastern white pine-western white pine	2.310	1.699	*0.736*	0.845	0.104	*0.123*
Eastern white pine-sugar pine	5.000	4.194	*0.839*	0.781	0.132	*0.169*
Western white pine-sugar pine	2.207	0.880	*0.399*	0.924	0.102	*0.110*
All white pine-ponderosa pine	0.579	0.381	*0.658*	1.179	0.096	*0.081*
All white pine-southern pine	0.137	0.024	*0.175*	1.287	0.135	*0.105*
All white pine-Douglas fir	0.219	0.102	*0.467*	1.4228	0.219	*0.154*

Source: Computations are based on the lumber production and price data in Steer, H. B. Lumber production in the United States 1799-1946. U. S. Dept. Agric. Misc. Publ. 669. 1948.

selves significantly modify prospective stumpage prices. Rather, stumpage prices will again be much more dependent upon what happens to the levels of demand for the different grades, provided, of course, that supplies are available in some amount.

The kinds of stumpage involved. Although we will estimate the future prices of sugar pine and western white pine, we are concerned particularly with estimating the most probable future prices of three "kinds" of eastern white pine stumpage: high-quality, low-quality, and medium-quality. Any one of these, or all three, might be produced from existing stands of second-growth timber in the Lake States. Even though it is silviculturally possible to grow all three grades of timber, it does not necessarily follow that growing all of them on any particular area will be economically feasible. The different kinds of stumpage would supposedly result from the application of several possible intensities of forest management, as well as the length of rotations.

High-quality stumpage. It is believed that with protection from blister rust and weevil damage, judicious pruning, thinning, and release, we might grow eastern white pine timber which, in average grade recovery though not in size, would approach the timber cut in the Lake States during the late 1920's and early 1930's. For our purposes, this would represent stumpage of high quality. It is generally acknowledged that this timber was not nearly so high in average quality as the 200- to 300-year-old "cork" pine cut during the 1890's. With early pruning we might actually be able to recover a fairly large percentage of quality lumber relative to total log volume. Just how large this percentage would be depends upon the length of rotation chosen. Table 3 compares grade recoveries from residual Lake States old-growth and New England second-growth, as well as western white pine old-growth timber.

Two facts are immediately evident from the table. First, the Lake States old-growth timber yielded three and one-half times as

TABLE 3. Grade recovery of second-growth and old-growth eastern white pine and old-growth western white pine.

Grade	Eastern white pine			Western white pine
	Lake States old growth[1]	New England second growth[1]	New England second growth[2]	old growth[3]
	percent			
Selects	11	2	3	15[4]
High common	33	17	12	34
Medium common	28	22	35	25
Low common	28	59	50	26
Total	100	100	100	100

[1]Davis, E. M. Lumber from old-growth versus lumber from second-growth in Pinus strobus. J. For. 38: 877-880, 1940. Grade recovery patterns are based on sample data covering old-growth timber cut in Minnesota during the period 1922-26 and second-growth timber cut in New England during the late 1930's.

[2]Average grade recovery from second-growth eastern white pine timber currently being cut in New England; estimated by Northeast. Lbr. Mfrs. Assn., August 16, 1955.

[3]Average grade recovery from old-growth western white pine estimated by Western Pine Assn. and used as grade weights in computation of western white pine price index.

[4]Selects include 2.9 percent of shops. Grade descriptions for eastern white pine from Lake States and New England and for western white pine are not strictly comparable, but are very similar. High common includes #1 and #2 common grades, medium common includes #3 common grade, and low common includes #4 and #5 common grades.

much select lumber, almost three times as much high common, somewhat less medium common lumber, and only about half as much low common lumber than does the second-growth timber currently being cut in New England. (See footnote 4 of Table 3 for definitions of low, medium, and high common lumber.) At least one-half of all lumber currently cut from this species is low-grade #4 and #5 common. Secondly, grade recovery from old-growth eastern white pine and western white pine was quite similar. Eastern white pine stumpage which approaches in grade recovery the residual timber that was cut in the Lake States or which resembles present western white pine timber will more than likely bring the future premium price. From this material would come the lumber which could satisfy the more exacting requirements of specialty products manufacture.

How closely we can duplicate the grade recovery pattern of residual old-growth eastern white pine or present western white pine depends not only upon how intensively management practices are applied, but also upon the length of rotation adopted. The managed forests of Europe may offer a clue to what qualities may be expected here if we grow eastern white pine under management over rotations of say 80 years. Grade recoveries would very likely run largely to high and medium common lumber. There would be less select lumber than was recovered from old growth, but also considerably less low common lumber than is currently being recovered from second-growth timber.

It is possible that managed eastern white pine timber could be higher in average quality than western white pine timber by 2010 if management of second-growth western white pine is delayed. Vaux (1954), in a study of sugar pine management possibilities, estimates that old-growth sugar pine would also be liquidated by 2010 and production would be based on second growth. As with eastern white pine, unless the stands are managed, future production of sugar pine would be reduced both in quantity and quality. Should this happen, markets for high-quality eastern white pine would be further enhanced and reduced competition would very likely be reflected in higher stumpage prices.

Low-quality stumpage. If existing second-growth eastern white pine stands in the Lake States are merely protected from blister rust with no attempt to reduce weevil damage or to improve timber quality, the lumber recovered from the resulting stumpage cut in the year 2010 can reasonably be expected to resemble in average quality the lumber recovered from current merchantable stands. As noted in Table 3, only about 15 percent of all the lumber cut from New England second-growth eastern white pine is select or high common lumber; of this, only 3 percent is select grade. By far the largest proportion, 80 to 85 percent, is medium or low common grade with fully 50 percent grading no higher than #4 common. As noted earlier, future market prospects for this grade of lumber are not nearly as promising as for the higher grades. Relatively low-quality stumpage will almost surely bring lower prices. To a certain extent, low-quality eastern white pine stumpage demand might also benefit from a decrease in competition from western and southern stumpage, but the benefit would be small compared to that for high quality stumpage. Very likely it will still be necessary to ship large volumes of lumber into eastern markets in order to satisfy anticipated large increases in lumber consumption. It will be much easier to augment eastern stock piles of low-quality lumber than high-quality lumber from other regions.

Medium-quality stumpage. Eastern white pine of medium quality is the kind of timber we would expect to grow if present stands are merely protected from blister rust and weevil damage. Since little if any pruning or thinning would be undertaken in these stands, neither the quantity nor

quality of the stumpage would compare with that grown under more intensive management. Because the lumber produced from this stumpage could be used for fewer exacting purposes and because it would be subject to greater competition from lower grade material, its demand and price would be lower than that of high-quality timber. However, in comparison with low-grade eastern white pine stumpage, medium-grade stumpage could reasonably be expected to bring a higher price.

The Stumpage Price Estimating Technique

Before going into the stumpage price estimating technique itself, a brief recapitulation of the main assumptions discussed so far will be helpful. These are:

1. The demands for eastern white pine lumber and stumpage are considerably influenced by the demands for the other white pines and ponderosa pine because all are good substitutes in use.
2. The demand for each kind (quality) of eastern white pine lumber or stumpage is probably very elastic, the demands for lower quality timbers being somewhat more elastic than timbers of higher quality.
3. Demand elasticities are not expected to change significantly between now and the year 2010.
4. Prices of white pine lumber and stumpage will depend more upon demand levels than upon differing supply levels.
5. Estimation of future demand levels for the white pines is synonymous with establishment of future prices for all practical purposes.

The analysis so far points out only that future demands and prices for high-quality lumber and stumpage will continue to be much higher than for the lower quality products; demands for medium-quality lumber or stumpage should be somewhere between these extremes. The purpose of the price estimating technique is to proceed one step further and to estimate these demand levels specifically *in terms of constant dollar prices*. This we may do within reasonable limits under the assumption that demands will continue to be very elastic in our target year.

The first step in this procedure involves estimating the future level of an aggregate price. All lumber prices and stumpage prices are more or less interrelated. It is unlikely, therefore, that we could realistically estimate the demands or prices of white pine lumber and stumpage without considering specifically some of the major forces which will govern the overall demand and prospective price level of all softwood lumber as well as the anticipated relationships between the white pines and all softwood lumber price. The variable chosen to represent the level of softwood lumber price is the Bureau of Labor Statistics' wholesale lumber price index.[5]

Estimation of aggregate lumber price. The first step in the derivation of eastern white pine stumpage price is estimating the expected change in the BLS wholesale lumber price index between now and the year 2010. It is immediately evident that much the same problem exists here as was noted in the earlier discussion of how one should go about estimating the future price of a particular kind of lumber. A complete economic model which would describe aggregate lumber price formation would

[5]An index of softwood lumber price as such is unavailable. The BLS index which includes both softwood and hardwood lumber is heavily weighted to softwoods (about 85 percent softwoods, 15 percent hardwoods). Because of this, it is believed appropriate for our use. The correlation between the BLS index and a price index composed of southern pine, Douglas-fir, and ponderosa pine (the most important softwood species by volume) was 0.996 over the period 1915-1950 (excluding 1942-1946). This means that 0.99 percent of the variation in softwood lumber prices was associated with movements of the BLS wholesale lumber price index. Statistically, it appears that anticipated movements in the BLS wholesale lumber price index will represent pretty well movements in softwood lumber prices.

also be complex. Furthermore, the dearth of information needed statistically to fit such a model is almost as pronounced in this case as before.

The demand for lumber considered as a whole may be somewhat less complex in that lumber as such has relatively fewer substitutes than an individual species. It is not possible to assume that this demand is completely elastic; certainly it is not nearly as elastic as the demand for a particular kind of lumber. In theory we are again faced with the problem of describing lumber supply and demand at the same time. It is not yet possible to develop and also to fit a suitable model which will estimate future overall lumber price in accordance with economic theory. But it is possible to develop simpler mathematical expressions that can be used.

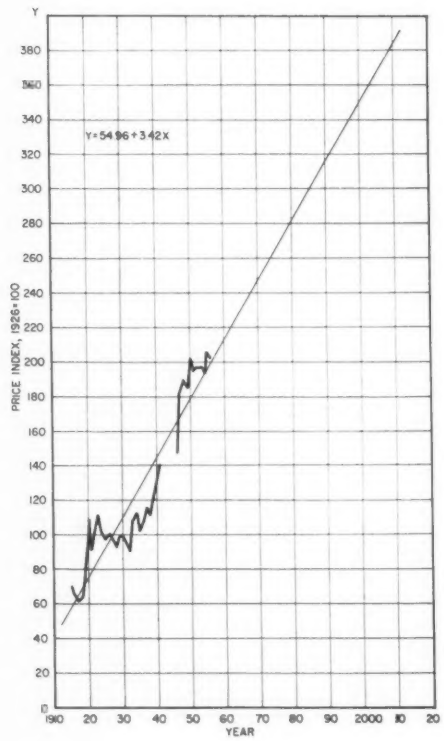

FIGURE 7. *Relationship of adjusted BLS Wholesale Lumber Price Index (1926 = 100) and time, 1915-2010.*

Present recourse to simpler mathematical expressions with which to approximate the formation of the overall price of lumber are not completely appropriate. They are, however, considered to be more appropriate than the estimation of the future price of a particular kind of lumber because the actual formation of individual prices is relatively more complex. The formation of eastern white pine lumber price, for example, involves not only the factors which govern the aggregate price of lumber, but also all the complications arising out of the competitive nature of eastern white pine lumber markets. Several formulations which might be used to estimate the future level of the Bureau of Labor Statistics' wholesale lumber price index are considered below.

Method 1—extrapolation of a linear trend of lumber price and time. Figure 7 shows the deflated Bureau of Labor Statistics Wholesale Lumber Price Index (1926 = 100) plotted over time.[6] A least squares trend line ($Y = 54.96 + 3.42X$) has been fitted to these data. For the range of data used, 1915-1956 (including World War II), the fit is statistically "good" ($r = .90$). If this trend line is extrapolated, the increase in deflated lumber price is about 34 percent over 1952 by 1975 and 94 percent by 2010. If 1956 is chosen as the base year, the increases are about 30 percent by 1975 and almost 90 percent by 2010.

This technique, as do the others to follow, requires the assumption that past price determining factors will continue to operate in the same way into the target period. Although it is believed that lumber prices will continue to rise for some time, the rate of price increase will more than likely decline as time goes on. With this tech-

[6]BLS data are adjusted for changes in purchasing power of the dollar by deflating with the BLS "all commodities" price index, 1926 = 100.

nique there is no way whatsoever of evaluating future price movement in the light of anticipated changes in the various lumber demand or supply factors.

Relating lumber price to various independent variables. Lumber price can be related to one or more "independent" variables and estimating equations worked out. An example of one of the simpler formulations would be a graphic relationship between adjusted lumber price (BLS wholesale lumber price index deflated by BLS' all-commodities price index, 1926 = 100) and "relative consumption" of lumber. Relative lumber consumption here means per capita consumption in terms of board feet relative to per capita consumption of all physical-structure materials measured in constant dollar quantity units. The Forest Service (1958), using U. S. Bureau of the Census estimates of annual consumption of all physical-structure raw materials (1900-1952), developed such a relationship and estimated consumption of lumber (production less exports, plus imports, and adjusted for changes in stocks after 1928). Using this relationship and lower level estimates of the potential demand[7] for lumber and physical-construction materials, the Forest Service estimates that lumber price (in constant 1926 dollars) by 1975 would be 38 percent higher than during 1948-52, and 97 percent higher by the year 2000.

This method requires independent estimates of lumber consumption and physical structure materials before the price estimate can be made. If, as implied earlier, lumber and competing material prices and consumption do not occur at any one time as independent phenomenon but as a result of the simultaneous interaction of a number of supply-demand factors, then this method is open to question. Furthermore, the method as developed assigns all the past variation in lumber price to changes in relative consumption of lumber. This procedure is not tenable in the light of even our present limited knowledge as to how lumber price and consumption are influenced.

The adjusted Bureau of Labor Statistics' wholesale lumber price index (1926 = 100) may also be related to per capita consumption of lumber as derived from Forest Service consumption data and a principal demand shifter say, the adjusted Department of Commerce and Labor (1956), (1958) expenditures for construction on a per capita basis.[8] The use of per capita data is an attempt to account for economic growth without introducing another variable such as population or gross national product. The objective here is to account for the principal variation in aggregate lumber demand by considering changes in volume of construction, the variable most responsible for lumber market fluctuations.

Using a relationship worked out with these variables for the years 1915-1941 and assuming a per capita lumber consumption of about 220 board feet (population 215 million and the Forest Service lower level estimate of potential lumber demand of about 47.6 billion board feet) and per capita adjusted expenditures of about $225 (1926 dollars) by the year 1975, the estimated lumber price would be about 10 percent over 1952 by that year. Using the lower level demand projection for the year 2000 would yield a lumber price increase of about 60 percent.

The use of this method also requires independent estimates of per capita lumber consumption and expenditures for construction in the target period. Estimating future

[7]The term "potential demand" as used by the Forest Service does not refer to demand in the usual economic sense, but to the estimated quantity of timber products that consumers might be willing and able to buy at specified future dates.

[8]In this formulation also all value data were adjusted by deflating with the BLS "all commodities" index (1926 = 100) instead of the index on the 1947-49 = 100 base, since the latter has not been officially computed further back than 1926.

expenditures for construction, however, does not involve the conceptual problem involved in estimating future per capita lumber consumption independently of future lumber price. Generally, the magnitude of construction expenditures is not believed to be significantly influenced by lumber price; i.e., it can be regarded as an "independent" variable in the equation. Independently estimated lumber consumption cannot be so considered, however.

In the equations so far mentioned, one of the errors in estimating lumber price where consumption is assumed to be an independent variable arises because the empirical results may not be descriptive of the true shape of lumber demand. Stated another way, the coefficients between price and consumption computed from such simple models may not yield reasonable estimates of demand elasticities. If so, these models may not perform well where change in lumber price is to be estimated, given an independent estimate of lumber consumption. Reliable estimates of lumber demand elasticities will not be available until much more fundamental lumber demand research is undertaken. From previous reasoning, however, if demand elasticity for lumber is actually quite high, the introduced bias may not be very important. This is because with elastic demand, only small price changes are associated with relatively larger changes in consumption. On the other hand, if demand elasticity is relatively low, the use of an independent estimate of consumption to help estimate price may introduce a substantial bias.

The lower level Forest Service estimate of potential lumber demand assumes an increase in the price of lumber relative to competing product prices and a continuing decline in relative consumption. This implies that demand for lumber has been and will continue to be relatively elastic, without prescribing the degree of elasticity. One may, if he wishes, accept the future lower level potential demand estimates as approximations of the volumes of lumber that might actually be consumed in the target periods, assuming that future consumption of competing products (hence, future competing products prices) have already been taken into account.[9] In this case the results obtained from the last formulation could be viewed as first approximations to future lumber prices. These are consistent with lower level potential demand assumptions regarding demand elasticity and growth in the national economy.

A third formulation involves adjusted lumber price, per capita lumber consumption, and per capita construction expenditures as before, but in addition an index of lumber manufacturing cost. This model attempts to account for an important demand shifter, volume of construction; and an important supply shifter, cost level of lumber manufacturing.[10] Inclusion of cost of lumber manufacture allows for considering, at least approximately, the effects of future processing costs on potential lumber price. Costs of manufacturing lumber here means cost per thousand board feet of sawing, planing, edging, etc. at the mill. It does not include cost of logs, logging, or stumpage. Unfortunately, suitable log and logging cost data are unavailable.

The lack of suitable cost data which could be used to determine the influence

[9]Inclusion in this formulation of a composite index of lumber competing materials as another variable would seem like a logical procedure and could be done. If so, however, estimation of future lumber price would require again a separate estimate of the future level of this composite index.

[10]It can be argued that from a theoretical viewpoint, it may not be strictly appropriate to include cost of lumber manufacture, which is a supply variable, in the same equation as expenditures for construction which may be considered a demand variable. However, since we are not proposing to "identify" our equation as either a demand or a supply equation, but merely an approximate price prediction equation, this argument may be less important. The cost data used originate with the Forest Service and Southern Pine Association and are not available in published form for general distribution.

of logs, logging, and stumpage on lumber price is particularly unfortunate. It is readily apparent that the cost of logging influences log costs, and these in turn influence lumber price through costs of manufacturing and lumber supply. The role of stumpage cost is not so clear, however. Before World War II, when stumpage was much more readily available in relation to stumpage demand than later, the relationship between lumber and stumpage price was not strong despite the fact that the price of stumpage ordinarily represents a residual value; i.e., the difference between lumber price and logging and processing costs. Before 1940, stumpage prices remained low, while lumber and log prices generally rose. Where stumpage is plentiful in relation to demand, its price may not significantly influence lumber price, but instead will be partly determined by the latter.

Although stumpage prices are residually determined in a short-run period, over the long run they can also be influenced by changed timber supply-demand conditions. In the postwar period when demand for stumpage increased relatively more than the demand for lumber, price of stumpage rose rapidly. Log prices have also become much more expensive and price of lumber has been indirectly influenced through higher manufacturing costs.

At any particular level of demand, the level of processing costs does directly influence lumber supply and, hence, lumber price. In the lumber industry rising processing costs, especially in the postwar period, have contributed to an increasingly inelastic lumber supply. The lumber manufacturing process and distribution organization have not been sufficiently improved to raise productivity rapidly and keep costs of manufacturing down as labor and other charges increase. Lumber supply has tended to decline, total demand has expanded, and lumber price has risen sharply.

Two important factors other than rising log costs are: rapidly rising labor charges, and decreasing raw material quality.

Making a competitive lumber product today requires that more time be spent in manufacture than formerly, partly because timber quality is lower. For some time to come we can expect log quality and supply to continue downward and labor costs to rise. At the same time there will probably be some counter trends working to increase productivity and keep lumber supply more flexible. The factors most likely to influence these counter trends are (1) a continuation of an industry trend toward larger, more efficient mills; (2) better use of raw material through industrial integration and development of new uses for wood; (3) continued development of better plant layout with better lumber manufacture and distribution; and (4) eventual production of larger volumes of managed timber.

Whether these trends will be strong enough to effect some stabilization in rising lumber processing costs is a matter of conjecture. Unless the lumber industry makes much more rapid progress along these lines than it has in the past, costs will continue to rise for some time. *A 10 percent rise by 1975* and a *25 percent rise* by the year 2010 are probably conservative estimates.

Relating adjusted lumber price to per capita lumber consumption, per capita construction expenditures, and lumber manufacturing costs over the years 1915-1941, an equation of the following form was worked out:

$$X_1 = 23.8 - .105X_2 + .700X_3 + .400X_4 \quad (R = .80)$$

In this equation X_1 is the adjusted BLS wholesale lumber price index (1926 = 100), X_2 is the annual per capita lumber consumption, X_3 is the adjusted annual per capita expenditures for construction (1926 = 100), and X_4 is the index of lumber processing costs (1926 = 100). Using this equation, the same 1975 levels of per capita lumber consumption (200 board feet), and expenditures for construction (225, 1926 dollars) as before, and assuming further a 10 percent increase in

the cost of manufacturing index over the 1952 level (191), adjusted lumber price would increase about 17 percent between 1954 and 1975.

For our selected target year, 2010, the assumptions regarding the future magnitudes of the independent variables would be as follows:

1. Gross national product would reach 830 billion (1926 dollars) by 2010 if between 2000 and 2010 it increases 13 billion per year, the estimated average annual increase between 1975 and 2000.

2. Total expenditures for construction (including maintenance and repair) would reach about 109 billion (1926 dollars) by 2010 if they constitute 13 percent of gross national product, the average proportion prevailing over the period 1915-1952 (excluding 1932-35 and 1942-46). Over this period the relationship between GNP and total construction expenditures has been very close ($R = .985$).

3. Population in 2010 might be 300 million, 25 million more than in 2000. This assumes that the annual rate of increase between 2000 and 2010 will be the same as between 1975 and 2000. Per capita construction expenditures might be about $360 (1926 dollars).

4. Total estimated consumption of lumber might be 60 billion board feet. This is about 10 percent more than the lower level estimate of potential demand for 2000 and assumes no further decline in lumber use relative to other materials after 2000. Thus per capita lumber consumption would be about 200 board feet.

5. The index of lumber manufacturing costs is expected to increase at least 25 percent over the 1952 level to 218.

Substituting these values into our equation, estimated lumber price, X_1, is computed as follows:

$$X_1 = 23.8 - .105X_2 + .700X_4$$
$$= 23.8 - 21.0 + 252.0 + 87.2$$
$$X_1 = 342.0$$

The lumber price index (on the 1926 base) in 1952 stood at 197. According to our estimate of 342, lumber prices will increase about 74 percent by the year 2010. Expressed in terms of the 1947-49 base (in constant 1947-49 dollars), the index in the year 2010 would be around 185. This is the estimate used in computing future lumber and stumpage prices.

Estimation of future price of eastern white pine stumpage. The following discussion concerns the second step in the price estimation procedure, i.e., the derivation of eastern white pine stumpage prices in line with the notion that future eastern white pine lumber and stumpage prices are merely components of the future white pine price structure; and further that future prices of most kinds of lumber and stumpage will be largely influenced by the future overall level of lumber price. This phase deals specifically with an examination, evaluation, and projection of the past ratios of (1) white pine lumber prices to the BLS wholesale lumber price index, and (2) white pine stumpage prices to their respective white pine lumber prices.

Given an estimate of the future BLS lumber price index level, any particular future white pine lumber price can be estimated through multiplication of the BLS lumber price by a projected ratio of that lumber price to the BLS price. In turn any particular future stumpage price may be computed through multiplication of lumber price by a projected ratio of stumpage price to lumber price.

Ratios of prices of white pine lumber to the BLS lumber price index. Figure 8 shows the ratio of lumber price to BLS lumber price for western white pine, sugar pine, Lake States eastern white pine, and New England eastern white pine over the prewar period 1915-1941 and the postwar period 1949-1956. There are no postwar (World War II) data for Lake States eastern white pine lumber because stumpage supply was generally exhausted by 1934. Lumber price data for sugar pine, western white pine, and eastern white pine for the period before World War II are from Steer (1948). Postwar lumber price

data for sugar pine and western white pine are drawn from the Western Pine Association's index prices of western species. For New England eastern white pine lumber the data are derived from summarized information on lumber prices published in the Commercial Bulletin (Boston). It is important to remember that the f.o.b. prices paid for sugar pine and western white pine in both the prewar and postwar periods and for Lake States eastern white pine in the prewar period apply to lumbers of relatively high average quality. For eastern white pine cut in the Northeast, they refer to a relatively low-quality lumber product. Later references to stumpage prices for these species may be similarly interpreted.

There is a notable absence of trend in ratio size for all species except New England eastern white pine in the period before World War II. This does not mean that the ratios have not varied in size from year to year, for there appears to be a scatter around the fitted trend lines, especially for sugar pine. The absence of significant secular trend (as measured by the statistical significance of the simple correlation coefficients at a 5 percent level of confidence) does indicate that ratios did not become consistently larger or smaller over the time period as a whole, except for New England eastern white pine. In the case of the latter the implication is that over time, when the BLS lumber price index rose, the average price of New England eastern white pine lumber did not rise proportionately; when the BLS price fell, the price of eastern white pine lumber fell further.

The decreases in ratio size for both New

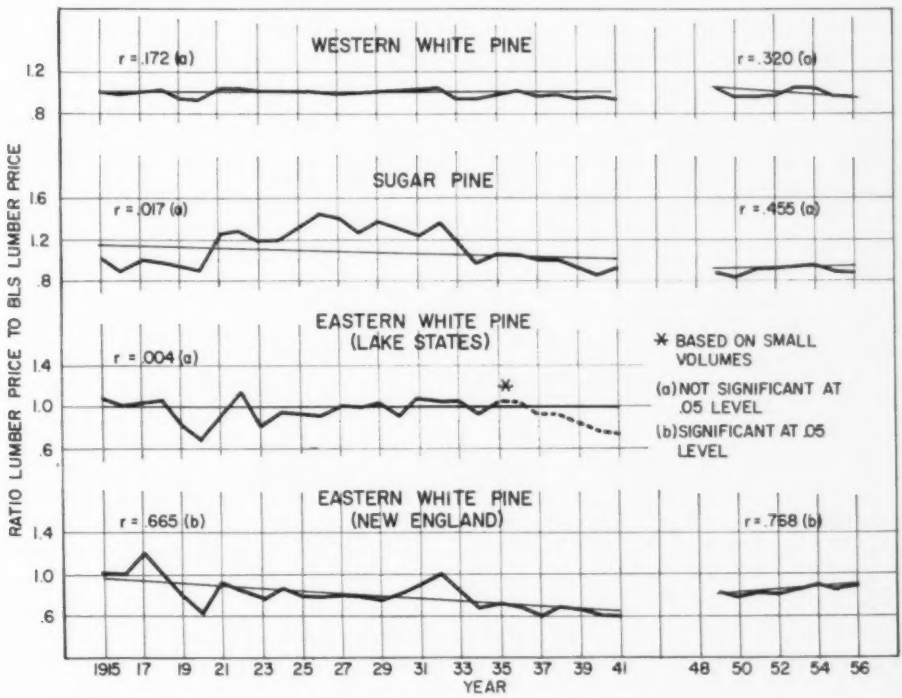

FIGURE 8. *Ratios adjusted lumber prices (1947-49 = 100) to adjusted BLS Wholesale Lumber Price Index, 1915-1956 (excluding 1942-1948).*

England eastern white pine and sugar pine are probably related to the declining use of box lumber. With sugar pine the fall in price relative to the overall lumber price level may stem from the fact that grade recovery for this species runs heavily to box grades. With the market for this material declining in the years before World War II, the average price of sugar pine lumber was also somewhat depressed in relation to all lumber prices. A similar situation has held for New England white pine, where for many years large volumes of low-grade, low-price lumber were sawed round-edge for further manufacture into boxes. With little or no recovery in the higher grades, the average price relative to the overall lumber price fell significantly with the decline in the box markets.

Apparently, the more stable demands for western white pine and Lake States eastern white pine have been derived from a continuing demand for the higher quality material produced from these species. At least the quality of lumber produced did not decline any faster than the quality of all lumber considered together. These species have continued to be marketed widely, and their price fluctuations tended, on the average, to follow the rise and fall of the overall lumber price index.

In the postwar period the situation appears to be different. Whereas the ratios for western white pine and sugar pine have remained stable at levels not very different from the prewar situation, the ratios for New England white pine have gradually increased indicating that the prices of this lumber has been increasing more rapidly than the index of all lumber prices. Although the evidence is not conclusive, this situation may be rationalized as follows:

1. The price paid for graded construction lumber was much higher than the price previously paid for round-edge, ungraded box lumber. The market for the latter has been substantially reduced in the Northeast.

2. Increasing volumes of #2 and #3 common lumber have been regraded and finished as knotty pine paneling and sold at much higher prices. After World War II, the demand for such material increased substantially and the higher price received for it has tended to lift the average lumber price for New England eastern white pine.

The size of ratios of future white pine lumber price/BLS index price may differ from those of today to the extent that some lumber prices relative to the overall price of lumber are changed. Assuming, for example, that trends in forest management and lumber manufacture in the western white pine region keep pace with developments industry-wise, and further that demands for other western softwood timbers are also enhanced by western economic growth, then the postwar ratio of 1.025 for western white pine might not be significantly changed. If the average quality of western white lumber should decline substantially either because present young stands go unmanaged or lumber manufacture fails to improve, then the future ratio would be smaller. The present ratio for sugar pine may be somewhat modified by 2010 even if sugar pine stands are managed and lumber efficiently manufactured.

Referring once more to Figure 8, it will be noted that while the trends in postwar ratios of lumber price to the BLS lumber price index for western white pine are very similar to the trend before World War II, the prewar and postwar levels for sugar pine differ. The ratios for sugar pine average higher before the war than afterwards. Average sugar pine lumber prices in the postwar period have actually been lower than western white pine prices, whereas before the late 1930's the reverse was true. The situation for sugar pine is likely to continue into the future unless new uses can be developed for some 32 percent of all sugar pine lumber which grades out shop or common, those grades which before World War II were widely used for containers. If the present situation continues, the future ratio for sugar pine may resemble the postwar average, 0.930.

In the year 2010 if the average grade

recoveries for managed eastern white pine and western white pine are similar and both species continue to be used for similar purposes, then their ratios of lumber price/BLS lumber price would tend to be fairly close. However, chiefly because of the expected reduction in regional competition from western white pine, the ratio for high-quality eastern white pine lumber may be as much as 10 percent higher than the ratio for western white pine or 1.100. This difference would be still larger if average quality of western white pine timber actually does fall significantly or if production declines to a very low level.

The ratio for low-grade eastern white pine lumber has averaged about 0.860 in the postwar period. To the extent that low-grade eastern white pine lumber may also benefit from reduced western competition, the ratio of lumber price/BLS lumber price index for this material may be maintained at about its present level or slightly higher, 0.875. The ratio for medium average grade eastern white pine lumber might be about 0.980, somewhere between the high- and low-quality ratios.

Transportation costs are an important part of retail and wholesale lumber prices, and they will likely continue so. Should transportation charges on western species sold in eastern markets be substantially raised in the future, a further advantage would accrue to eastern white pine lumber. The postwar ratios of lumber price to BLS lumber price for the western species would not necessarily be greatly changed by increased transportation costs because the BLS index is heavily weighted by western lumber f.o.b. prices (and will no doubt continue to be so weighted). Presumably all western species would be similarly affected by increased transportation charges. However, the presently estimated differences between ratios of western lumber price/BLS price and those for eastern white pine lumber/BLS price might be increased, since f.o.b. prices for western lumber would be lowered, while prices of eastern white pine lumber would not. Thus to a certain extent eastern white pine lumbers could gain some market advantage, and their demand elasticities would become somewhat less than previously proposed. Eastern white pine stumpage demand elasticities would be similarly affected.

Even though transportation costs have risen substantially since 1946, it is difficult to say whether or not they will actually continue to rise more rapidly than lumber price or the prices of all commodities. The less costly movement of lumber by truck is becoming more important and may help to keep freight charges down. Furthermore, more efficient milling and distribution may help to counter this effect of increasing transportation costs on lumber and stumpage prices.

Ratio of white pine stumpage prices to white pine lumber prices. Figure 9 shows ratios of stumpage price to lumber price for western white pine, sugar pine, Lake States eastern white pine, and New England eastern white pine. Sources of the lumber price data used in computing these ratios are the same as for the ratios in the previous section. Stumpage prices over the prewar period are based on private sales as reported by Steer (1938), (1931-43). Stumpage prices for western white pine and sugar pine in the postwar period are derived from National Forest stumpage sale records compiled by the Forest Service. Suitable postwar data on eastern white pine stumpage prices are not available. The plotted data indicate that the prewar and postwar trends are different and that before the war the trends for western white pine and sugar pine are different from the trends for white pine cut in the eastern states.

With respect to western white pine and sugar pine, the plotted data suggest that over the prewar period 1921-41, the relationships between lumber and stumpage prices have remained essentially unchanged. In contrast to sugar pine and western white pine, the prewar trend lines for Lake States and New England white pine are negatively sloping. The data suggest that the

ratios of stumpage price to lumber price tended to become smaller. It is likely that demands for eastern white pine stumpage decreased more rapidly than demands for eastern white pine lumber, especially for the lower quality material. This could very well have come about in this period because of increasing costs of conversion and logging, increasing competition from western softwood species shipped to eastern markets in large volume, and the steady loss of the once important box market.

The decline in the ratio of stumpage price to lumber price for Lake States eastern white pine from 1915 to 1934, when cutting virtually ceased, appears to have been less rapid than for the New England product over a like period. This is probably due to the fact that logging and conversion costs per thousand board feet were lower in the Lake States, where the terrain is easier, logs were larger and of better quality, and the mills generally of larger size. Furthermore, because Lake States lumber was of higher average quality than the New England product, it was not quite so dependent upon a declining box market and could be channeled into other more stable uses.

Figure 9 also suggests that the ratios for western white pine and sugar pine have been changing rapidly in the postwar period. The very marked upward sloping trend lines indicate that prices of stumpage have risen further than lumber prices. This situation has arisen partly because demand for available supplies of accessible stumpage has increased more rapidly than demand for lumber. Operators increased their demands for timber over and above the volumes needed to satisfy augmented demands for lumber and other industrial wood probably in anticipation of a tighter stumpage market and higher timber price.

A second factor contributing to rapidly increasing stumpage prices has been the growing awareness on the part of stumpage owners that their raw material has become much more valuable. Many more sales than formerly are being made on a bid basis. Greater frequency of bid sales has had the effect of boosting stumpage prices.

How long stumpage prices in general continue to increase faster than lumber prices is a matter of conjecture. Harvest and conversion costs are expected to increase somewhat despite industry efforts to increase productivity, and higher costs will eventually act to limit stumpage price increases relative to increases in lumber prices. On the other hand, stumpage prices may continue to be bid up for some time as demand increases in response to expanding demands for lumber and other industrial wood, especially if trends toward consolidation and blocking up of forest holdings continues and substantial volumes of private timber are held off the market in order to build up growing stocks. Pressures on sawtimber may be somewhat tempered if the use of small softwood timber, low-grade hardwood trees, and mill and logging residues for pulps is significantly expanded. Between 1941 and 1956, the proportion that stumpage price was of lumber price has about doubled for sugar pine and western white pine. Further increases in the ratio of stumpage price to lumber price may be small.

Increased western demands relative to eastern demands by the year 2010 for sugar pine and western white pine imply that relatively more of these timbers will be used in the West than is the case today. Western white pine lumber would still have to bear transportation costs to the east or west, but sugar pine would not if most of it were sold within the West Coast states. An increase in the present ratio of stumpage price to lumber price for sugar pine would appear to be more promising than for western white pine.

The trend values of the ratios of stumpage price to lumber price for western white pine and sugar pine were almost the same by 1956 (0.330). If it is assumed that for sugar pine this value will increase only a little more, say about 5 percent over present levels, the future ratio would be 0.345.

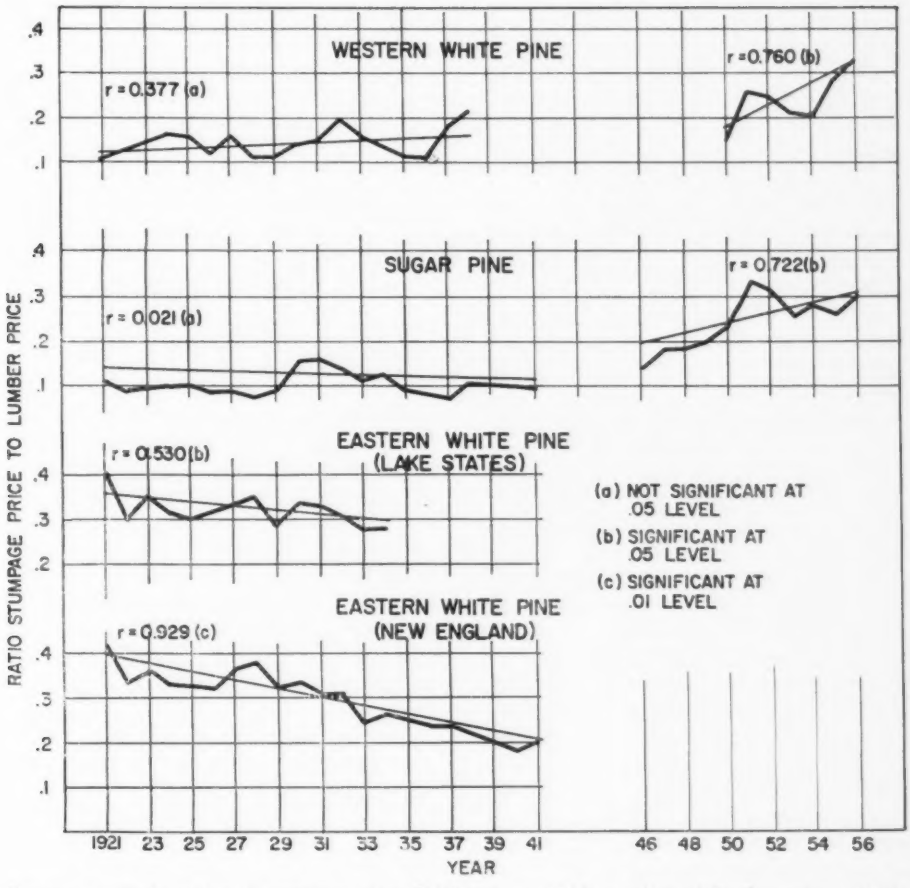
WESTERN WHITE PINE
r = 0.377 (a)
r = 0.760 (b)
SUGAR PINE
r = 0.021 (a)
r = 0.722(b)
EASTERN WHITE PINE (LAKE STATES)
r = 0.530(b)
EASTERN WHITE PINE (NEW ENGLAND)
r = 0.929 (c)
(a) NOT SIGNIFICANT AT .05 LEVEL
(b) SIGNIFICANT AT .05 LEVEL
(c) SIGNIFICANT AT .01 LEVEL
RATIO STUMPAGE PRICE TO LUMBER PRICE
.4
.3
.2
.1
1921 23 25 27 29 31 33 35 37 39 41 46 48 50 52 54 56
YEAR

FIGURE 9. *Ratios adjusted stumpage prices (1947-49 = 100) to adjusted lumber prices, 1921-1956 (excluding 1942-1945).*

For western white pine, because of added lumber transportation charges, the ratio might be somewhat lower, about 0.340.

The potential ratio for high-quality eastern white pine is much more difficult to estimate directly because postwar data are lacking. An examination of prewar data shows that over the period 1921-41 the average ratio of stumpage price to lumber price for Lake States eastern white pine was 0.160 higher than the ratio for western white pine. In terms of constant 1947-49 dollars, Lake States stumpage sold for an average of $7.75 more than western white pine, even though western white pine lumber usually sold for more than did Lake States eastern white pine lumber in this same period. Most of this difference in stumpage price probably represents higher logging costs per thousand board feet in the West; some of it also represents the cost of shipping western white pine lumber to eastern markets.

If, as assumed by this study, the lumber produced from managed eastern white pine stands will be similar in average quality to

the western white pine product in the target period, differences in stumpage prices between these two species will once more represent differences in costs of logging between the two areas and an improved regional market position for eastern white pine. It may not be unreasonable to assume that eastern white pine of high quality will be worth at least $10 more per thousand (in constant dollars) than western white pine stumpage of similar quality.

Estimation of the probable size of the ratio of stumpage to lumber price for low-quality eastern white pine is also difficult. Again there is a lack of postwar information on stumpage price. Because of the rise in price of New England eastern white pine lumber in the postwar period, it is likely that stumpage prices have also risen. New England mill operators generally attest to this fact. Furthermore, there is good reason to believe that stumpage prices have tended to rise more rapidly than lumber prices as is the case for the western species. However, unlike the ratio of stumpage to lumber price for high-grade eastern white pine, which could be tied to the ratio for western white pine, size of the future ratio for low-grade eastern white pine must be estimated independently.

It is likely that by 1955 or 1956, the ratio of low-grade eastern white pine stumpage price to lumber price had recovered to about 0.275 or better over the low of 0.200 reached in 1941. If the ratio continues to appreciate gradually as demand for construction lumber in eastern markets increases, and more western and southern lumber is consumed in other regions, it might reach 0.300 by the target period. This is about the ratio value prevailing in the early 1930's before the decline of the box market. It is unlikely that its value would be much higher than this. Per unit logging and conversion costs are bound to increase not only because labor and equipment costs will rise, but also because densities in unmanaged stands would tend to be light, quality and size of trees would be low, and mills in the Lake States will probably remain small. Whether or not it will even be possible for producers of only low-average quality eastern white pine lumber to pay higher prices for stumpage and still stay in business depends to a considerable degree upon how effectively this industry can hold down future production costs.

The ratio of stumpage price to lumber price for medium quality eastern white pine might be somewhere between the ratios for low- and high-quality timber, about 0.340.

Estimated White Pine Lumber and Stumpage Prices in the Year 2010

Multiplication of the projected BLS lumber price index (185) by the estimates of the various ratios of white pine lumber price/BLS lumber price gives the estimated lumber prices per thousand board feet in the year 2010 in constant 1947-49 dollars shown in Table 4.

Calculation of stumpage prices is carried out in a similar manner, multiplying white pine lumber prices by the stumpage price/lumber price ratios to yield stumpage prices in the year 2010 in 1947-49 dollars. If

TABLE 4. Estimated lumber prices in 2010 in constant 1947-49 dollars.

Species	BLS price ratio for 2010 lbr. price	Est. lbr. price in 2010 (dollars)
Sugar pine	0.930	172
Western wh. pine	1.025	190
Eastern wh. pine		
High quality	1.100	204
Medium quality	0.980	180
Low quality	0.875	162

TABLE 5. Estimated stumpage price in 2010 in constant 1947-49 dollars.

Species	Stumpage price ratio	Est. stumpage price in 2010 to nearest dollar
Sugar pine	0.345	60
Western wh. pine	0.340	65
Eastern wh. pine		
Medium quality	....	75
High quality	0.340	60
Low quality	0.275	45

the present worth of a future stumpage price expressed in actual or current dollars is desired, it may be secured by (1) discounting the future price in 1947-49 dollars back to the proper year, say 1956, at some appropriate interest rate, and (2) multiplying the discounted value by the all-commodities wholesale price index, 1947-49 = 100, for the chosen year. Estimated stumpage prices in the year 2010 (in constant 1947-49 dollars) are shown in Table 5.

Summary

Forecasting price for any commodity is a difficult and frequently a disappointing undertaking. Yet there are many occasions when some estimate of future value can serve a useful purpose, even if the estimate is at very best, only a rough approximation. The more widespread adoption of forest management on privately held woodlands in order to enhance future timber supply may very well depend upon our ability to point out to the potential forest manager the possible economic alternatives available to him. In order to do this it must be possible to make comparisons of costs and returns. Estimates of future costs of alternative timber management procedures as well as returns from them are required.

It may some day be possible to make better forecasts of price within the dictates of economic theory where simplified economic models representing the price generating mechanisms are specified and quantified mathematically. Suitable knowledge and historical data are not yet available in sufficient detail to carry out this procedure for forest products. This type of forecasting has been done with varying degrees of success for certain basic agricultural products, however.

This analysis has dealt with an alternative method for estimating the future prices of three quality grades of eastern white pine stumpage and sugar pine and western white pine. Economic demands for these products are not described mathematically, but the future prices as estimated do represent potential demand levels in terms of dollars if it is assumed that demands for these commodities will be highly elastic over a reasonably wide range of prices. Demands for high-, medium-, and low-quality eastern white pine stumpage are believed to be very elastic because they have several good substitutes in use; viz., western white pine, sugar pine, ponderosa pine, Douglas-fir, and all softwoods considered together. The technique has a further advantage in that price estimates can be made without considering directly all the supply possibilities.

In the method used an estimate of the future Bureau of Labor Statistics' wholesale lumber price index in constant dollars was made first. From this value the future prices of the several white pine lumbers were made, also in constant dollars, utilizing projected ratios of white pine lumber prices to the BLS lumber price. Future stumpage prices were derived from lumber prices by applying projected ratios of stumpage prices to lumber prices.

According to the study results, stumpage prices by the year 2010, in constant 1947-49 dollars, for sugar pine will be about $60 per thousand board feet; for western white pine, $65; for high-quality eastern white pine, $75; medium-quality, $60; and low-quality, $45.

The estimated future stumpage prices reflect, in general, some continuation in increasing importance of stumpage value relative to lumber price over the next 50 years. According to our estimates, lumber prices may increase 65 to 75 percent over the next 50 years; i.e., at a rate somewhat less than during the period 1915-1956. Stumpage prices may double over this period. If the estimated rate of lumber prices increase is too high, future lumber demands will, of course, be affected. In this case stumpage price may not rise as far as estimated. However, if past experience is any guide, our estimates may actually be conservative.

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